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AN ANALYSIS OF SEDIMENT SHEAR STRENGTH.(U)

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NO. 86

"AN ANALYSIS OF SEDIMENT SHEAR STRENGTH"

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"AN ANALYSIS OF SEDIMENT SHEAR STRENGTH"

A Trident Scholar Project Report

by

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ABSTRACT

The part played by laboratory testing in the successful application of underwater soil mechanics to problems concerning ocean engineering depends both on the uniformity of the natural strata and on the skill and experience of the engineer. The empirical relationships developed in terrestrial soil mechanics for designing foundations and determining soil mass stability are based to a major extent on ~~the~~ triaxial tests, while virtually all data on marine sediments have been acquired ~~utilizing~~ using ~~the~~ vane shear tests. The standard vane shear test has been ~~the~~ most widely used ~~test~~ because it can be performed quickly, with a minimum of sample disturbance, and the equipment is relatively simple and inexpensive. Although both the triaxial test and vane shear test are used to determine the shear strength of soil, thus far there has been virtually no correlation established between these two tests.

This study concerns the determination of laboratory shear strength for a ~~particular~~ marine soil, and evaluates the relationship between the vane shear test and triaxial test results. The ability to correlate these data with data from other triaxial and vane shear tests should prove to be a significant contribution to the field of soil mechanics and ocean engineering. For the particular sediment tested (a clayey silt), the initial tests indicate the vane shear peak strength to be 10% of the triaxial test peak shear strength, however, thus far, the writer has found virtually no correlation between the two tests.

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INTRODUCTION

One of the most recent developments in the field of soil mechanics and foundation engineering is the emergence of the study of marine soils. The emphasis for this development has been supplied by demands associated with the expansion of the offshore construction industry, both in the civilian and the military arena. These demands are a direct consequence of environmental studies, an increase in population, the need for development of offshore petroleum and mineral resources, and for the military, the desire to utilize the seafloor for interests of national security.

Until recently, most of the information available concerning marine soils was the result of investigations conducted by marine geologists and oceanographers. These investigations were undertaken to determine the geophysical and geological characteristics of marine soils, and are thus of limited value to practicing soil engineers. Investigations specifically directed to the finding of the engineering properties of marine soils were almost exclusively undertaken by oil companies, consulting firms, governmental agencies, and only a handful of college universities. With the exception of university-type research, these early investigations were, more often than not, designed to facilitate specific projects and were therefore of limited value in adding to the general knowledge concerning the engineering properties of marine soils.

The determination of shear strength is of utmost importance in soil engineering practice, both in the laboratory and in the field. Both have limitations, however. Proper tools needed for adequate field testing are not available, and laboratory testing is taken at the risk of

sample disturbance, thus leading to inaccurate results. Laboratory testing is also very expensive because of the cost of obtaining samples. Unless a soil test simulates the worst conditions which will exist IN SITU, it may not reflect the soil strength at its poorest (the strength ordinarily needed for design). Furthermore, it is often difficult if not impossible in a field test to include the effect of future changes in soil strength imposed by construction. The effects of environment and future load changes can be studied in the lab, however. Any program of field testing should be correlated with tests in the laboratory conducted under the full range of loading and environment at conditions which will likely be experienced. Similarly, no lab program of soil testing is complete without field verification by strength tests.

It should be emphasized that the purpose of this analysis is to make a comparison between two types of sediment testing apparatus - the triaxial test and the vane shear test - and NOT to simply obtain the strength characteristics of a particular type of soil, since this procedure is common in engineering practice today. In order to accomplish this objective and obtain accurate data, both the existing triaxial test apparatus and vane shear apparatus at the U. S. Naval Academy were modified to enable a wide range of loading conditions, to have a more effective loading system, and to allow electronic printouts, graphical and digital, of the test data. In order to establish a correlation and to gain a theoretical understanding of the differences between the two tests, a specially designed triaxial thrust rod was modified so that standard triaxial tests, standard vane shear tests, and combined vane shear/triaxial tests may be run in one complete test apparatus. Although

this modification was not tested in this study, it is highly recommended that a future analysis in this particular area of soil behavior include this equipment for testing.

DESCRIPTION OF SEDIMENT

The sediment used for this analysis has been kept in a large storage container, and has been used repeatedly over the past few years in previous soil investigations. It is an olive-grey clayey silt taken from the continental shelf off the coast of California, in the Santa Barbara Channel, at a depth of 600'. It consists of 3% sand, 25% clay, and 72% silt. It has a permeability of 2.5×10^{-7} cm/sec, and a coefficient of consolidation of 1×10^{-3} cm^2/sec. The liquid limit is 48.6, the plastic limit is 30.0, and has a void ratio of about 1.0 in a remolded state. This data was taken from previous work done by Midshipman James Halwachs, a Trident Scholar in 1972. Thorough remolding of the sample was accomplished by utilizing a heavy-duty mixer. Because this particular study was oriented around testing the equipment and not the soil in particular, there was no harm in reusing the soil, provided that the remolding was thorough and complete.

PROCEDURE

The project was divided into three general categories:

1. First Data Set
2. Second Data Set
3. Construction of modified triaxial thrust rod

1. FIRST DATA SET

A. Preliminary measurement of the peak shear strength of the soil sample was performed in the sample tray by obtaining four vane shear tests at 0.8" from each corner of each prospective sample to obtain an average shear strength for the particular sample.

B. An average value of all 72 vane shear tests was obtained to normalize future data. The normalizing was performed by correcting the data found from the triaxial tests, using the average vane shear strength found from each separate sample. If the vane shear test results were above the average of all the tests, the normalized value was the percentage addition or subtraction to the particular test result.

C. The specimen sample was taken out of the sample tray using a coring device, and the "hole" was filled with a wooden plug of equal dimensions as the sample to prevent possible future disturbance in the tray.

D. A water content analysis was performed on a ¼" sample of the test specimen, and the sample was placed in the triaxial cell and consolidated. Four different pressures were used: 25 psi, 50 psi, 75 psi, and 90 psi. The purpose was twofold: (1) to simulate different sediment depths, and (2) to obtain a normalized Mohr envelope for the soil for both total and effective stress. Consolidation time was initially

varied between 4 hours and 24 hours to determine whether or not the time of consolidation was a factor in the determination of the peak shear strength of the soil, but the time was held constant for later tests at 4 hours, for reasons of consistency in data.

E. Eighteen consolidated undrained triaxial tests were run at the four different pressures, first at rates of testing between 60 minutes and ten hours to obtain the variations in peak deviator stress and pore water pressure with time, then at a constant rate of 45 minutes to obtain consistent data. Triaxial failure was assumed at 20% strain.

F. A vane shear test was then run on the failed triaxial sample to establish correlations between the undrained shear strength from the triaxial test and the undrained shear strength from the vane shear test. The results were plotted as follows: peak shear strength vs. normal stress found from the Mohr envelope. See Appendix D.

G. Another water content analysis was performed on the failed sample following the triaxial and vane shear test to determine the effect of water content on peak strength and consolidation pressure. See Appendix C for numerical results and Appendix D for graphical results.

H. All data was collected, the results are found in Appendix C, D and F. Results are discussed in the Summary section of this paper.

2. SECOND DATA SET

A. Four tests were performed in the triaxial cell at pressures of 25 psi, 50 psi, 70 psi, and 75 psi. The same procedures of test rates, vane shear tests, and water content analysis were used as in the first data set. The purpose of this data set was to obtain greater uniformity in the sediment samples as the first data set had wide variations in the

initial shear strength measured in the sample tray. The soil specimens were again remolded, which caused a lower peak shear strength than the first data set, but a consistency could still be determined. The results plotted for this data set are as follows: peak shear strength vs. normal stress, water content vs. confining pressure, and axial stress vs. water content. As in the first data set, there was nearly a 10 to 1 variation between the peak shear strengths found from the triaxial test vs. the vane shear test, i.e. the vane shear strength found was still only 10% of the triaxial shear strength. See Appendix C, D, and F for results.

For each vane shear test performed, both peak shear strength and remolded shear strength were recorded using a digital voltmeter and strip chart recorder. (See Appendix B and Appendix E for further description of equipment and pictures of the apparatus, see Appendix G for sample strip chart printout of vane shear test).

For the consolidated undrained triaxial test, the data was obtained from the gauges found on the apparatus itself. The data was as follows: confining cell pressure, axial load (using the load ring affixed atop the triaxial cell - see Appendix E), axial stress - found from dividing the axial load by the initial cross sectional area of the soil specimen, strain rate using a dial indicator, and pore water pressure using a pore water pressure measuring device. The vane shear test rate was held constant at 0.0262 rad/sec (90 deg/min) for all vane shear tests. Earlier studies have indicated that, as the rate of shear decreases, the shear strength also decreases, due to the phenomenon of creep, and perhaps a change in pore water pressure.

3. CONSTRUCTION OF MODIFIED TRIAXIAL THRUST ROD

This was a design problem, the purpose of which was to enable vane shear tests to be performed in the triaxial cell at the same time a triaxial test is run. This modification may enable determination of whether a shear using the vane shear apparatus will cause an increase in pore water pressure, and to find the effect of pore water pressure on the vane shear test to determine whether or not a drained condition actually exists.

The thrust rod was designed for a vane to be coupled to the bottom of the rod, with a fixed connection resting on the top stone, separated from the thrust rod itself by roller bearings. A hole in the center of the top pore stone of the triaxial cell, with a slightly larger diameter than the vane shaft, was also created to allow the vane shaft to enter the soil sample directly. The top of the thrust rod was fitted with a gear to be connected with a similar gear on the vane shear strain gauge. The entire vane shear apparatus was then to be placed on a modified wooden platform adjacent to the triaxial apparatus.

SUMMARY OF RESULTS

The following tables represent a summary of results found from test data sets 1 and 2. The first table shows in tabular form all data collected from data set #1. The second table gives the corrected values of specific parameters due to normalization from data set #1. Table #3 indicates the results of water content tests for data set #1. Table #4 gives the results for data set #2, showing the water content results, vane shear strength results, and triaxial test results. Table #5 is the Mohr envelope for data set #1; table #6 is the Mohr envelope for data set #2. See Appendix C, G and H for further tabular results.

TEST DATA COLLECTED FROM DATA SET #1

Test #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Peak avg. τ fm VANE SHEAR TEST	(psi) .77	.64	.82	.83	.43	.61	.72	.55	.61	.51	.53	.55	.71	.67	.54	.71	.67	.49
Remoulded avg τ fm VANE TEST (psi)	--	--	--	--	--	.26	.16	.20	.26	.31	.30	.34	.40	.34	.29	.47	.40	.23
TRIAXIAL cell press. (psi)	50	50	25	--	75	50	50	50	75	25	10	25	75	90	25	50	75	90
time of TRIAXIAL TEST	1 hr	10hr	3hr	--	9hr	2hr	45min	2hr	45min	45min	45min	45min	45min	45min	45min	45min	45min	45min
AXIAL STRESS @20% strain	(psi) 53.6	117.7	28.3	--	106.1	57.65	67.15	67.16	79.36	35.1	11.39	29.4	80.17	96.4	49.0	53.97	78.52	98.8
Pore Pressure @ 20% ϵ (psi)	8.0	7.0	2.4	--	14.0	--	7.0	6.5	10.0	6.0	2.0	7.5	6.0	5.0	2.0	3.0	10.0	8.0
σ_1 @ failure (20%E) (psi)	45.6	110.7	25.9	--	92.1	--	60.1	60.7	69.4	29.1	9.4	21.9	74.2	91.4	47.0	51.0	68.5	90.8
σ_3 @ failure (20%E) (psi)	42.0	43.0	22.6	--	61.0	--	43.0	43.5	65.0	19.0	8.0	17.5	69.0	85.0	23.0	47.0	65.0	82.0
Water content before test	--	.29	.35	--	.41	.33	.44	.37	.38	.42	.32	.35	.42	.42	.39	.36	.43	.24
Water content after test	--	.25	.28	--	.32	.24	.37	.29	.37	.27	.33	.34	.37	.28	.28	.33	.27	.14
Average water content	--	.27	.31	--	.37	.28	.41	.33	.37	.34	.33	.34	.39	.35	.33	.35	.35	.19
Change in (%) water content	--	16.4	23.0	--	27.2	39.7	19.0	27.2	3.5	59.0	3.1	1.7	14.5	49.5	40.1	9.0	60.7	69.4
Peak τ fm V.S. AFTER TRIAXIAL (psi)	--	--	--	--	--	.85	1.0	1.1	1.1	.45	.45	.55	1.3	5.0	.8	1.1	.85	2.8
Remoulded τ fm. V.S. after triaxial test (psi)	--	--	--	--	--	.3	.5	.35	.7	.25	.25	.2	.7	.45	.35	.3	.5	1.4
Deviator stress $(\sigma_1-\sigma_3)$ (psi)	3.6	67.7	3.3	--	31.1		17.1	17.2	4.4	10.1	1.4	11.6	5.2	6.4	24.0	4.0	3.5	8.8
Total stress σ_1 psi	53.6	117.7	28.3	--	106.1	57.6	67.1	67.1	79.3	35.1	11.4	29.4	80.2	96.4	49.0	54	78.5	99
Total stress σ_3 psi	50	50	25	--	75	50	50	50	75	25	10	25	75	90	25	50	75	90
% τ above/below avg. from V.S.	22%	1.6%	30.1%	--	31.7%	3.2%	14.3%	12.7%	3.2%	19%	16%	12.7%	12.7%	6.3%	14.3%	12.7%	6.3%	22%

CORRECTED VALUES DUE TO NORMALIZATION OF VANE SHEAR STRENGTH TEST DATA FROM TEST SET #1

TEST #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
% difference fm. V.S. avg	22%	1.6%	30.1%	-	31.7%	3.2%	14.3%	12.7%	3.2%	19%	16%	12.7%	12.7%	6.3%	14.3%	12.7%	6.3%	22%
CORRECTED (psi) values for σ_1	65.4	115.8	36.8	-	106.1	59.4	67.1	75.6	81.8	41.8	13.4	33.1	90.4	102.5	42.0	60.9	83.4	120.8
TOTAL (psi) stress (σ_3)	50	50	25	-	75	50	50	50	75	25	10	25	75	90	25	50	75	90
Corrected deviator stress (psi)	15.4	65.8	11.8	-	31.1	9.4	17.1	25.6	6.8	16.8	3.4	8.1	15.4	12.5	17.0	10.9	8.4	30.8
time of (min) triaxial test	60	600	180	-	540	120	45	120	45	45	45	45	45	45	45	45	45	45
PEAK PORE pressure (psi)	6.24	7.11	3.0	-	18.3	-	6.0	7.32	10.3	7.12	2.3	8.45	6.76	6.31	2.3	3.64	10.63	9.76
Effective horiz. stress (psi)	43.8	42.9	21.0	-	56.7	-	44.0	42.7	64.7	17.8	7.7	16.5	68.2	83.7	22.7	46.4	64.4	80.2
Effective vertical stress (psi)	59.2	108.7	14.8	-	87.8	-	61.1	68.3	71.5	34.7	11.1	24.7	83.6	96.2	39.7	57.3	72.8	111.0

Data #: Set	2 Before	2 After	3 Before	3 After	4 Before	4 After	5 Before	5 After	6 Before	6 After	7 Before	7 After	8 Before	8 After	9 Before	9 After	10 Before
wt. (g) paper	.35	.7	.6	.5			.5	.8	.7	.6	.5	.5	.7	.8	.8	.8	.9
wt. paper & wet soil	60.87	103.6	30.50	47.3			41.3	90.0	90.3	67.8	118.6	105.0	62.3	114.5	120.5	101.0	26.8
wt. paper & dry soil	50.40	83.2	22.8	37.0			29.4	68.9	68.0	54.9	90.7	76.6	45.7	88.9	87.6	74.1	19.1
wt. water	10.47	20.4	7.7	10.3			11.9	22.1	22.3	12.9	27.9	28.4	16.6	25.6	32.9	26.9	7.7
~~wet~~ dry soil	50.05	82.5	22.2	36.5			28.9	68.1	67.3	54.3	62.8	76.1	45.0	88.1	86.8	73.3	18.2
water content	.291	.250	.347	.282			.412	.324	.331	.237	.444	.373	.369	.290	.379	.366	.423

sample failure prior to testing

WATER CONTENT ANALYSIS FOR EACH SAMPLE BOTH PRIOR TO AND FOLLOWING TRIAXIAL TEST. FOR DATA SET #1

[Note: No water content analysis was performed on sample #1]

	10 After	11 Before	11 After	12 Before	12 After	13 Before	13 After	14 Before	14 After	15 Before	15 After	16 Before	16 After	17 Before	17 After	18 Before	18 After
wt. paper	.9	.7	.9	.8	.5	1.0	.9	1.0	.9	.6	.6	1.0	.9	.8	1.0	.9	1.0
wt. paper & wet soil	110.0	53.9	77.9	106.8	66.6	49.2	38.3	63.1	99.3	72.5	102.0	102.5	66.0	14.0	93.2	70.3	62.1
wt. paper & dry soil	87.0	40.9	58.9	79.4	49.7	35.7	28.3	44.8	77.8	52.4	80.0	72.7	49.7	10.0	73.6	56.7	54.4
wt. water	23.0	13.0	19.0	27.4	16.9	14.5	10.0	18.3	21.5	20.1	22.0	29.8	16.3	4.0	19.6	13.6	7.7
wt. dry soil	86.3	40.2	57.0	78.6	49.2	34.7	27.4	43.8	76.9	51.8	79.4	81.7	98.8	9.2	72.6	55.8	53.4
water content	.266	.323	.333	.349	.343	.418	.365	.417	.279	.388	.277	.364	.334	.434	.270	.244	.144

DISCUSSION OF RESULTS

Upon normalization of data for the first data set, there was found a remarkable consistency in the Mohr envelope diagram, with the exception of the tests run at 25 psi. It is not known why this data was inaccurate; perhaps further testing will yield better results.

The data for the graph of peak shear strength after triaxial loading versus water content after triaxial loading was consistent with other soil test data from other sources, indicating an increase in water content with a decrease in peak shear strength, although separate points were plotted for each confining pressure. Normally, all the data points should have fallen on one curve. This was not the case in this data, however.

In correlating the water content versus confining pressure, there was a reasonable amount of consistency, as the graph indicated a gradual decrease in water content with an increase in confining pressure, which was reasonable, as an increase in pressure would cause more water to be squeezed out of the soil sample during the consolidation phase of testing.

One of the reasons for varying the length of time required for testing was to investigate the effect of peak pore water pressure with time, and these results were consistent with those found from other soil tests. As the length of time required for testing increased, the pore water pressure would reach a peak value near the 2¼ hour mark, and gradually decrease with time. This indicates that for the optimum measurement of the effect of pore water pressure, all future tests should run somewhere between two and three hours for this type of sediment, instead of 45 minutes - the length of time this test series was run.

The graph of peak deviator stress with time caused a great concern, as its behavior was the opposite of the intended behavior. There should have been a gradual decrease in peak deviator stress with time; however, this was not the case in this analysis. The possible, and most likely reason for this behavior was due to a lack of sufficient consolidation time for the tests, and all future tests in this area should allow a minimum of 24 hours for sample consolidation in the triaxial cell, instead of the 4 hour allotment utilized in this analysis.

The final graph of the first data set, which was the goal of our analysis, pertaining to the peak shear strength found with the vane shear test versus normal stress on the Mohr diagram, gave extremely interesting results. It indicated approximately a 10 to 1 variation between the shear strengths of the triaxial test and the vane shear test, i.e., the vane shear test had its peak shear strength to be only 10% of the peak shear strength found from the triaxial test. There is a certain lack of confidence in these results, however, as from theory, there should have been a more direct correlation between the two shear strengths. It should be noted that there has been little previous relationship established between these two tests on marine sediments. The lack of confidence also results from a definite variation in consistency in comparing each of the separate test results.

As these results were rather questionable, a second data set was obtained by running four more test runs at four different confining pressures, to see if the results would be similar in nature to the first test data set. As the soil was remolded again, there was a lower shear strength found from these results, but once again the comparison of the

two shear strengths were found to be close to the first data set. The Mohr diagram showed the peak shear strengths to be nearly 10% of the first set. The water content showed the typical increase with a decrease in peak shear strength after triaxial loading, though at a much steeper slope on the graph. This was because all four data points were put on one line, rather than obtaining one line for each confining pressure.

Once again, the water content decreased with an increase in cell pressure, as in the first data set. Finally, the relationship between the triaxial vs. vane shear tests had close to a 10:1 variation in peak shear strength, though a little less, because of remolding. These results were not average values, and the data points were not as consistent as the first data set.

Since there has been little previous relationship investigated between the shear strength found between the triaxial and vane shear tests on marine sediment, there are no direct correlations to base my data upon. It is therefore highly recommended that more research be done in this area to either support or refute these research results. Recommendations call for: 1) allowance in increasing consolidation time for each test to a minimum of one day, 2) to avoid the use of a sample tray which may have been a major source of inconsistencies in shear strengths, and 3) to run the vane shear tests inside the triaxial cell under confining pressure using the modified apparatus, rather than taking the sample out of the cell after triaxial failure and then running a vane shear test. This procedure may have been another result in variation with expected results.

Other variations could have been due to the possible sample

disturbance after remolding, sometime during the preparation of the sample before testing; the friction in the system, which was not measured, as it was assumed to be constant throughout the test process; and the slight possibility of leakage in the system, which may have occurred although one month was devoted to leak prevention in the triaxial cell, its fittings, and the pore water pressure measuring device.

CONCLUSIONS

It is apparent from the results found in this analysis that further testing needs to be performed, in order to be confident of these initial findings. Thus far, there has been virtually no correlation between the triaxial and vane shear tests, so there has been no other data to compare these results with. If these findings are indeed valid, new areas of analysis must be made correlating the two tests, as present day soil engineers would be greatly underestimating and wrongly predicting soil behavior for this particular type of sediment from one type of test alone.

It is also necessary to enable the vane shear test to be performed inside the triaxial cell utilizing the modified thrust rod designed in the course of this study. This will provide more accuracy in determining the true vane shear strength, as the soil will still be in the pressurized state inside the cell.

It was found that the sample tray was not a good method for obtaining consistent samples, and should not be considered for future testing. Variations in the shear strength found from the vane shear tests on the tray samples indicated a lack of consistency and wide variation in shear strength.

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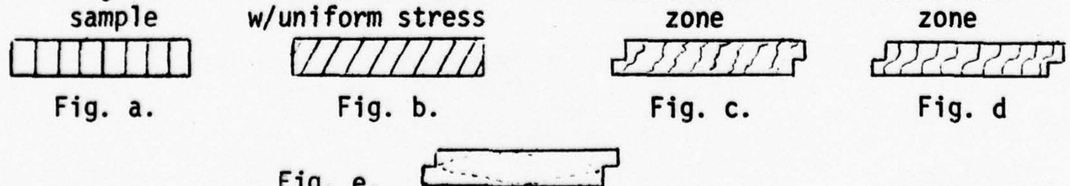
APPENDIX A

DESCRIPTION OF TRIAXIAL TEST

MECHANISM OF SHEAR

If a specimen is failed in a pressure system such that there is no uniform distribution of stress on the failure surface, the entire strength of the specimen is not mobilized simultaneously for resistance to failure. Instead, the specimen is failed progressively, like the tearing of a piece of paper. Because progressive failure is fostered by non-uniform stresses and strains, it follows that the test which imposes the most uniform conditions on the test specimen will have the least progressive action.

Figure a. shows a direct shear specimen before the start of shear. If the strains were uniform, the sheared specimen would be as shown in Figure b.; the vertical lines remain parallel but move to the position shown. The strains of Figure b. however, are not the actual ones, but those of Figures c. and d. are. In fact, the shear zone of a direct shear specimen seems to be contained within the dotted lines of Figure e.. The soil at the edges of the box is usually failed before the soil at the center is close to failure.



original sample — Fig. a.

ideal failure w/uniform stress — Fig. b.

thick shear zone — Fig. c.

thin shear zone — Fig. d

Fig. e. shear zone from direct shear machine

(AFTER LAMBE, 1969)

Although the distribution of strains and therefore, stresses, is more nearly uniform in the triaxial test, it is not completely uniform. Figure f. shows the cross section of a loaded triaxial specimen. Because of the restraint furnished by the sample caps (in our case, the top and bottom porous stones), there are dead zones at the top and bottom in which practically no strains occur. The center zone, therefore, undergoes considerably greater strain than the edges; this is illustrated by the scales on the specimen, which were alike before shear. As a result of this strain distribution, the stresses in the center of the specimen are greater than those at the edges.

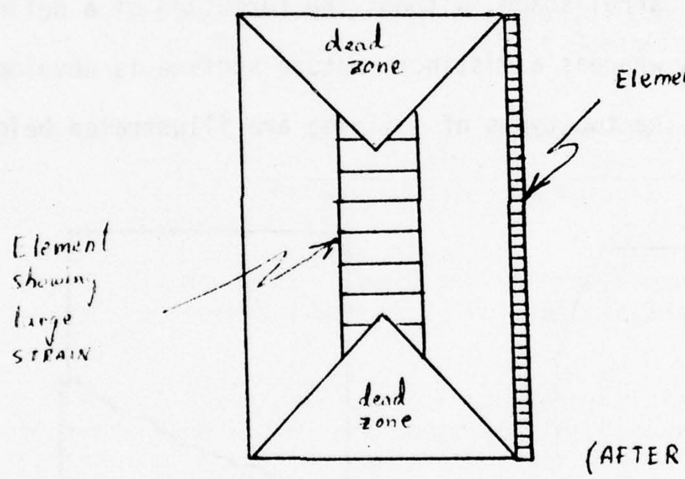
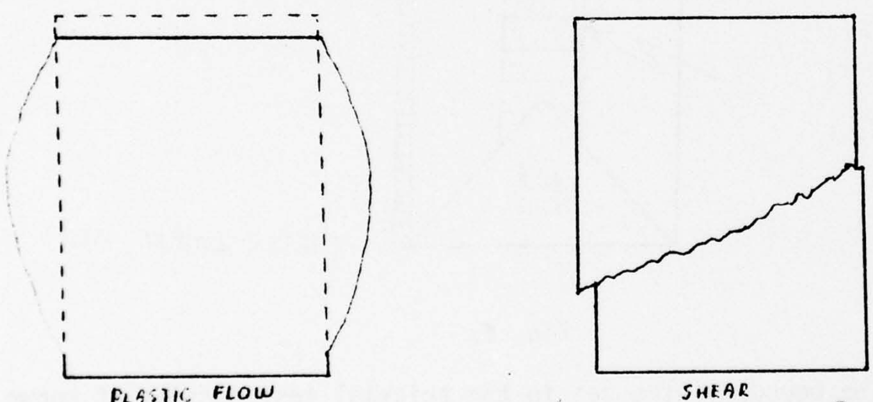


Fig. f.

Since the boundary stresses in the triaxial test consist of known normal pressures and zero shear stresses on the horizontal and vertical planes, the complete stress system is always statically determinate in this test. The principal stresses on the test sample are controlled by two means: σ_1 is applied and controlled by a loading ram, or thrust rod at a strain-controlled rate, and σ_2 and σ_3 are controlled by varying

the pressure inside the cell; therefore $\sigma_2 = \sigma_3$. Another way of expressing what has been stated is to point out that a Mohr diagram can be drawn for any stage of the triaxial test, as long as another factor, known as the pore water pressure, is known. Pore water pressure will be discussed in detail in a later section of this paper. The changes of stress on any plane can be traced as the test progresses, unlike, for instance, the direct shear test, where only the failure conditions are known and the only known stresses are the horizontal ones.

A triaxial specimen may fail in one of two general ways: a plastic flow failure or a shear failure. In a plastic flow failure, the specimen bulges to a barrel shape, without the formation of a definite rupture surface, whereas a distinct rupture surface is developed in a shear failure. The two types of failures are illustrated below:



(AFTER LAMBE, 1969)

The failure of an undistrubed specimen is a shear failure, and that of a remolded specimen is a plastic flow failure. In this particular analysis, a remolded specimen was used for testing, and we obtained plastic flow failure in all cases.

There are four basic types of triaxial tests:

1. Unconsolidated drained tests
2. Unconsolidated undrained tests
3. Consolidated drained tests
4. Consolidated undrained tests

If the excess pore water pressures are positive so that the soil tends to decrease in volume, the process is called consolidation. The process of consolidation is governed by the equations of equilibrium for an element of soil, the stress-strain relations for the mineral skeleton, and a continuity equation for the pore fluid. This paper is concerning itself solely with the consolidated undrained triaxial test, whereby we consolidate our sediment sample under an all-around confining stress, and prevent any drainage to occur from the sample. This will allow us to measure the pore water pressure for any given state of stress, and therefore enable computation of the effective stress, which is simply the total stress minus the pore water pressure, or mathematically stating it:

$$\bar{\sigma} = \sigma - u$$

Where σ = total stress

$\bar{\sigma}$ = effective stress

u = pore water pressure

The majority of publications state that the normal time for running a consolidated undrained triaxial test (hereafter referred to as a CUT test) is about ten minutes if pore water pressure measurements are not required. If they are required, the time for testing may take from one to eight hours depending on soil type and the accuracy called for.

The consolidation stage of a CUT test may take as long as three days in a soil of low permeability, and it is important that variations

in cell pressure be avoided during this period. Our particular soil had a permeability of $K = 2.5 \times 10^{-7}$ cm/sec. For certain special tests, a constant cell pressure may be required for a period of several weeks or even months. The maintenance, with sufficient accuracy, of a constant cell pressure over a long period of time presents considerable difficulty. For the purposes of this analysis, the 90 psi air line system from within Rickover Hall, coupled with a 1200 psi air tank, was used for our experiments.

Current methods of applying the axial load to the sample are influenced both by the requirements of the particular test and the need for mechanical simplicity. Two classes of procedure may be broadly distinguished: controlled rate of strain and controlled stress. For routine tests and for the more common research tests, the use of the controlled rate of strain has many advantages and is generally accepted. Our work was performed on such a machine. The rate of strain at failure is accurately known, and the influence of rheological factors on the observed strength can thus be taken into account. The shape of the stress-strain curve beyond the point of maximum stress can also be observed. The duration of the test can be predicted with reasonable accuracy which, from the practical point of view, is important in planning the test program.

DESCRIPTION OF TRIAXIAL EQUIPMENT

Our testing was performed with the Karol-Warner Triaxial Model No. 567T, which consists of the Model No. 567 Compression tester modified specifically for triaxial testing of both soil and rock samples up to

4 inches in diameter and up to 9 inches high. Our soil samples for all tests were 2.75 inches in diameter and of varying heights, the most common height being 6.5 inches. The test machine has an axial capacity of 25,000 lb. and was fitted with a sensitive load ring for soil samples, which measured the axial load being applied. The sample is placed in the test chamber (which has a 400 psi lateral pressure capaicty) by removing the top of the test chamber, removing the windowed cylindrical chamber, placing the sample on the bottom porous stone, ensuring that the bottom stone is firmly in place to prevent leakage, and ensuring an o-ring or rubber band seal around the rubber membrane holding the sample on the bottom stone. The top stone is placed atop the sample, and secured with o-rings or rubber bands, and the two 1/16" tubes are firmly connected to the top stone before replacing the glass-walled cylinder, filling the interior of the cell with water if desired, and replacing the top and tightening it down with the four knurled nuts.

The base of the cell has one external fitting which is for the dry air supply. This fitting is internally connected to the air regulator into which an air supply is fed. The air pressure is read directly from the gage on the base. The dirve shaft for the cell platform is coupled to a variable D.C. motor, which drives the platform either up or down at 1120 rev/in.

As was mentioned previously, the top porous stone is connected to two tubes, which are led to couples on the outside of the cell. These are used for saturation of the sample, and for pore water pressure readings, when coupled to a pore pressure device. Normally, only one port needs to be open to the atmosphere during saturation, but saturation

can be performed quicker if both ports are left open to the atmosphere.

The thrust rod which applies the axial load is inserted through the top opening on the cell, and adjusted so as to fit into the hole on the top stone without disturbing the soil sample. It is held in place by a clamp which holds a strain gage until there is pressure added to the chamber via the air supply hose to the top male couple on the top of the cell. After lateral pressure is introduced into the cell, the clamp can then be loosened.

Behind the base of the triaxial cell is the Pressure Saturation Device, KWPS-1. This is utilized for measuring volume changes in the cell and sample, and is also used for saturation of the sample. For the purposes of this investigation, the volume changes were not recorded, and we only used the device for saturation of the soil sample. If volume measurements are desired, it is first necessary to calibrate the three tubes on the device by reading levels of known amounts of water added into the tubes. The water is added to the center tube after the gage at the top of this tube is removed. The left tube is filled by leaving open the two valves located on the bottom of the device. When both tubes are filled to the desired amount, close the left valve, replace the gage, couple the center tube to the lower porous stone, couple the upper stone to the atmosphere, and add pressure to the center tube via an airline to saturate the sample, ensuring that the saturation pressure is less than the lateral pressure inside the cell, or the sample will explode within the cell, and thus preventing a test from occurring.

When a steady stream of water flows from the upper stone (the atmospheric connection), uncouple the upper stone, and open the left

valve on the pressure saturation device. This outer left tube will be used to measure the volumetric changes in the sample by reading the change in water level in the tube.

The right tube is used to measure the volumetric change inside the chamber itself. Since this tube will be exposed to higher pressures than the center and left tubes, the right tube is constructed out of metal. The thin plastic tube on the outside is used to measure the change in the water level. Because the plastic tube is very thin, the force inside it is not as much as the larger metallic tube because of the smaller surface area of the thin tube. This tube is filled by unscrewing the bolt at the top and pouring water into the opening. The tube is connected to the test chamber while lateral pressure is being added to the chamber. When the chamber is pressurized, the hose applying the lateral pressure is then connected to the top of the right tube and the bottom of the tube is connected to the chamber top.

The pore water pressure measuring device consists of a stand containing a gage that measures pressures via a bourdon tube. Mercury is added with a syringe until it can be seen through the thin glass tube on the device. Prior to use, it is best to add pressure to the device to get rid of air pockets, and to check for mercury leakage. This was a major problem during the course of testing, and the device had to be repaired periodically. The mercury level in the thin glass tube is adjusted using a hand knob on the left side of the device, but should not be adjusted while testing is in progress. It is also highly recommended to calibrate this device using the air supply line for the triaxial cell and checking both gages (on the triaxial base and the pore pressure device) to ensure they are reading the same pressures.

APPENDIX B

DESCRIPTION OF THE VANE SHEAR TEST

MECHANISM OF VANE SHEAR TESTING

The great majority of laboratory and IN SITU measurements to determine sediment strength utilize the vane shear test. This test can be performed quickly, and as stated in the introduction, is simple and inexpensive. It has been found that vane shear tests have several deficiencies, however:

1. The tests are not applicable to granular sediment.
2. The vane failure surface is predetermined and vertical.
3. The vane failure surface that is assumed (a right circular cylinder) for sediment strength calculations is not accurate.
4. The size of the vane and the rate of shear is not standardized.
5. The conditions of drainage are not known. (Monney 1974)

The last two deficiencies are related and their significance can be evaluated by laboratory experiments. Monney (1974) recommended a standard shear rate of 0.0262 rad/sec, or 90 deg/min, and this rate was used throughout this analysis. The reasons for a standardization of the shear rate are as follows: One would expect the shear strength of a sediment to vary to some extent as the rate of shear is varied. A clayey sediment behaves as a viscoplastic material, and should exhibit an increase in strength as the rate of shear is increased. For sediment for which the vane shear test is applicable, a shear rate of 0.0262 rad/sec

will most likely result in an undrained shear failure. Slower rates of testing may result in partial drainage in some cases. Moreover, the change in strength with small changes in shear rate is very small near the rate of 0.0262 rad/sec. The changes in exhibited strength can be quite large for small changes in shear rate near the rate of 0.002 rad/sec. For example, a variation of ± 0.0009 rad/sec (3 deg/min) from the shear rate of 0.002 rad/sec would cause a shear strength variation of less than .1% (Monney 1974). This is important because most vane shear devices are not accurately rate controlled. Finally, the shear rate of 0.0262 rad/sec can be performed more quickly, which is particularly important when tests are being performed onboard ships, and long cores are being taken. Rates of testing will be discussed in greater detail in a later portion of this paper.

Changes in pore water pressure at the failure surface will also influence shear strength. If the pore water pressure decreases (as with a dense sediment where the grains must move apart to fail in shear), the effective stress between the grains increases and the shear strength increases. Conversely, if the pore water pressure increases (as with a loose-structured sediment where the grains are squeezed together in a shear failure), the shear strength decreases. It was found that in comparison of vane shear test rates between 0.0002909 rad/sec (1 deg/min) to 0.0262 rad/sec (90 deg/min) that shearing resistance varied significantly within these rates, therefore the 90 deg/min rate was decided upon as the standard rate for this analysis.

The vane shear test device was developed and tested in Sweden (Cadling and Odenstad, 1950). The measured torque on the vane shaft is

taken as a direct function of the shear strength utilizing the following assumptions:

1. The surface of failure is in the form of a right circular cylinder, with dimensions equal to those of the vane blade.
2. The stress distribution at maximum torque is everywhere equal and uniform about the cylinder surface.

With these assumptions, the equation follows:

$$T = \pi \times (H \times D/2 + D^3/6) \times \tau_f$$

where T = maximum torque

H = height of the vane blade

D = diameter of the vane blade

τ_f = shear strength at maximum torque

For this analysis, a Wykeham-Farrance Laboratory Vane Tester was modified to be driven by a variable D.C. motor with direct chain drive to the vane shaft. With this device, the rate of applied strain was rigidly controlled at predetermined levels. A bonded strain gage was coupled to the shaft of the vane for direct electrical printout of the torque on the shaft. The strain gage was connected to a Wheatstone bridge rectifier, which was connected to an amplifier, whose output was calibrated and measured on both a digital D.C. voltmeter and a strip chart recorder, in order to obtain both numerical and graphical results of the vane test.

Different methods of obtaining the shear strength of our particular sediment were attempted using the vane shear apparatus. Our sediment was remolded in a sediment tray of dimensions 24" long x 13" wide x 9" in depth. Fifteen soil samples of 2.75" in diameter each by 6.5" in

height could be withdrawn from the tray in this manner. Before taking each sample out of the tray and into the triaxial cell, four vane shear tests were run at each corner of the sample location, 0.75" from the sample core itself. This was done for each sample in order to obtain both the average shear strength of each sample, and to find an average shear strength within the tray itself. The results are as shown in the Appendix section of this paper.

Once the average shear strength was obtained, two possibilities of measuring the shear strength using the vane shear device in the triaxial cell were utilized. The first method attempted was to simply run the triaxial test on a sample to failure, then remove the top portion of the cell and immediately run a vane shear test through the top of the sample at a depth of 2.25" into the sample (the same depth used in finding the shear strength in the sediment tray). The second method was to incorporate the use of the vane shear device to allow the vane to be fitted to the thrust rod of the triaxial cell, and rotated within the cell utilizing two gears, one connected to the top of the triaxial thrust rod, the other connected to the strain gauge of the vane shear device. The vane shear device is to be mounted on a stand adjacent to the triaxial cell, and needs to be calibrated and adjusted to prevent gear slippage and miscalculations due to the torque caused by the two gears.

APPENDIX B(I)

DETAILED TEST PROCEDURE

The first step in the test analysis was to take four vane shear tests around each sample in the sediment tray prior to triaxial and subsequent vane shear tests. Each of the four vane shear tests were taken at a depth of 2¼" into the sample, at a distance of 0.8" from each corner of the sample. This test, as the other vane shear tests, was run at a standard rate of 90 degrees/minute. The purpose was to obtain an average peak strength for each sample prior to testing, and then to obtain an average of all the tests to be used for normalization of data results.

The coring device, of dimensions 2.75" in diameter by 9" high, extruded the soil sample, which was then lubricated and the rubber membrane was placed around the corer. The purpose of this was to facilitate the placing of the soil into the triaxial cell without the necessity of using the split membrane jacket. The sample was placed on top of the bottom pore stone, and secured with rubber "o" rings to the stone. An air line was connected to the coring device to force the test sample out of the corer via air pressure, so as the sample came out of the corer, the rubber membrane would surround the sample in its place. Before connecting the top porous stone to the sample, a ¼" slice was taken off the top of the soil sample, and a water content analysis was performed on it. The sample was then measured for proper height and diameter.

The top stone was then placed on top of the soil sample, "o" rings secured the stone to the membrane and sample, and the ¼" tubing jumpers connected tightly to the top pore stone. The metal cylinder of the

triaxial device was then replaced, the cell was then filled with water, the top of the cell screwed down handtight using the knurled nuts. The thrust rod was inserted through the chamber top, and carefully set in place through the hole on the top pore stone, ensuring no sample disturbance. The strain dial indicator was clamped to the protruding end of the thrust rod to prevent the rod from slipping and disturbing the sample. Once pressure is added to the system, the clamp on the strain dial can be loosened.

The cell was then placed on the triaxial platform-set on the brass plate and centered using the locating pin on the plate. The loading arm on the platform was then lowered until the stress dial indicator was touching the thrust rod. When the cell system was properly located on the triaxial platform, and no leakage of water appeared, cell pressure was then added by connecting the air line hose to the top of the triaxial cell (see picture - air hose is "A"). A waterline connection was set in place by connecting a hose from the pressure saturation device to the connection to the bottom pore stone (water line hose is "B" in picture). To facilitate saturation of the sample, a hose was connected from the top stone to the atmosphere (this hose is "C" in picture). Once these connections were in place, the center valve on the pressure saturation device was opened for water to run into the sample inside the cell, and saturation pressure was supplied via the air system in Rickover Hall, regulated by an air regulator located on top of the pressure saturation device (regulator is "D" in picture). Ensure that the saturation pressure is less than the cell pressure, or the soil sample will explode inside the cell. Once a steady stream of water emerges from the connection to the atmosphere, the atmospheric connection can then be taken off,

and the top stone can be connected to the pore water pressure measuring device (Device is "E" in picture, connection is "F"). If the sample is completely saturated, there should be a reading of zero psi on the pore pressure gauge. The waterline connection from the pressure saturation device should be disconnected at the same time the atmospheric connection is taken off. The triaxial test can then be performed.

Synchronize the start of the test with a stopwatch, switch on the load, and record the readings from the pore pressure device, the stress dial indicator ("G" in picture), and check the air pressure gauge to ensure the readings are not fluctuating ("H" in picture). Readings should be taken at a consistent time period, such as every five minutes for a 45 minute test, or ½ hour for 10 hour tests. The stress gauge does not give a direct readout of the axial stress; it is necessary to find the stress using a loading curve that comes with the load ring. The stress is found by taking the load reading from the load ring curve, and dividing by the cross sectional area of the soil sample.

The pore pressure reading is a direct reading on the gauge, but the strain must be found by taking the reading on the strain dial indicator and dividing by the initial length of the sample.

The desired rate of testing is found by determining the maximum strain desired for the particular test. If a 20% maximum strain at failure is desired, for a 45 minute test, a strain rate is found by realizing that .2x initial sample height will be the failure point. Hence, for our analysis, .2x 6.5" = 1.3" at failure. The strain rate is found by taking 1.3" and dividing by 45 minutes to get a strain rate of 0.0289"/min.

Once the failure strain has been reached, run the test for once more data point, then halt the strain motor on the triaxial cell, release the water from the cell using the front bottom connection on the cell with a hose, release the axial load by reversing the triaxial motor, and slowly release the air pressure from the cell.

The cell is removed from the platform, the thrust rod (letter "I" in picture) is taken out of the cell opening, the top of the cell is removed, the metal cylinder is removed, all the hose connections are removed, and the top stone is removed. The sample is now ready for the vane shear test.

The vane is inserted through the top of the failed sample, and inserted the same distance (2.25") into the sample as the previous vane shear tests. After the vane shear test is completed, another ¼" thick sample is taken from the center of the failed soil sample, and a water content analysis is run on it. This will give the change in water content from before the test.

Once the vane shear test and water content test is run on the failed triaxial sample, the sample may be placed back in the storage can, and another test is run.

APPENDIX B(II)

DESCRIPTION OF WATER CONTENT ANALYSIS

Water content of each test sample was obtained before and after each triaxial test. Water content is defined as the ratio of the weight of water to the weight of the solid in a soil taken from its natural surroundings. Natural water content is an easy characteristic to obtain, but is an important indicator of other sediment properties, such as shear strength.

PROCEDURE FOR DETERMINATION OF WATER CONTENT

1. Preweigh a small circle of paper (ensure the paper is larger than the size of soil to be analyzed).
2. Select a homogenous sample of sediment and place a consistent amount of it on the paper.
3. Weigh immediately to obtain the weight of the wet soil. Then place paper and soil on a dish, which is to be placed in a drying oven.
4. Allow sample to dry thoroughly, using a drying oven. Be certain to use the same amount of time for each soil sample to maintain consistent results, to ensure that ambient humidity does not cause calculations to be inaccurate. Recommended setting: 5, for a period of 1 hour.
5. Weigh the paper with the dried soil immediately.
6. The weight of the water is simply the weight of the paper with the wet soil minus the weight of the paper with the dry soil.
7. The weight of the dry soil is simply the weight of the paper with the dry soil minus the weight of the paper.
8. The water content is the ratio of the weight of water (step 6) divided by the weight of the dry soil (step 7).
9. Repeat this procedure for successive sediment samples. (See Appendix C, D, H).

APPENDIX C:

1. Summary of results from test set #1
2. Normalized data from test set #1
3. Water content data from test set #1

TEST DATA COLLECTED FROM DATA SET #1

Test #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Peak avg. τ fm VANE SHEAR TEST	(psi) .77	.64	.82	.83	.43	.61	.72	.55	.61	.51	.53	.55	.71	.67	.54	.71	.67	.49
Remoulded avg τ fm VANE TEST (psi)	--	--	--	--	--	.26	.16	.20	.26	.31	.30	.34	.40	.34	.29	.47	.40	.23
TRIAXIAL cell press.(psi)	50	50	25	--	75	50	50	50	75	25	10	25	75	90	25	50	75	90
time of TRIAXIAL TEST	1 hr	10hr	3hr	--	9hr	2hr	45min	2hr	45min	45min	45min	45min	45min	45min	45min	45min	45min	45min
AXIAL STRESS @20% strain	(psi) 53.6	117.7	28.3	--	106.1	57.65	67.15	67.16	79.36	35.1	11.39	29.4	80.17	96.4	49.0	53.97	78.52	98.8
Pore Pressure @ 20% ϵ (psi)	8.0	7.0	2.4	--	14.0	--	7.0	6.5	10.0	6.0	2.0	7.5	6.0	5.0	2.0	3.0	10.0	8.0
$\bar{\sigma}_1$ @ failure (20%E)(psi)	45.6	110.7	25.9	--	92.1	--	60.1	60.7	69.4	29.1	9.4	21.9	74.2	91.4	47.0	51.0	68.5	90.8
$\bar{\sigma}_3$ @ failure (20%E) (psi)	42.0	43.0	22.6	--	61.0	--	43.0	43.5	65.0	19.0	8.0	17.5	69.0	85.0	23.0	47.0	65.0	82.0
Water content before test	--	.29	.35	--	.41	.33	.44	.37	.38	.42	.32	.35	.42	.42	.39	.36	.43	.24
Water content after test	--	.25	.28	--	.32	.24	.37	.29	.37	.27	.33	.34	.37	.28	.28	.33	.27	.14
Average water content	--	.27	.31	--	.37	.28	.41	.33	.37	.34	.33	.34	.39	.35	.33	.35	.35	.15
Change in (%) water content	--	16.4	23.0	--	27.2	39.7	19.0	27.2	3.5	59.0	3.1	1.7	14.5	49.5	40.1	9.0	60.7	69.4
Peak τ fm V.S. AFTER TRIAXIAL (psi)	--	--	--	--	--	.85	1.0	1.1	1.1	.45	.45	.55	1.3	5.0	.8	1.1	.85	2.8
Remoulded τ fm. V.S. after triaxial test (psi)	--	--	--	--	--	.3	.5	.35	.7	.25	.25	.2	.7	.45	.35	.3	.5	1.4
Deviator stress $(\bar{\sigma}_1 - \bar{\sigma}_3)$ (psi)	3.6	67.7	3.3	--	31.1		17.1	17.2	4.4	10.1	1.4	11.6	5.2	6.4	24.0	4.0	3.5	8.8
Total stress σ_1 psi	53.6	117.7	28.3	--	106.1	57.6	67.1	67.1	79.3	35.1	11.4	29.4	80.2	96.4	49.0	54	78.5	99
Total stress σ_3 psi	50	50	25	--	75	50	50	50	75	25	10	25	75	90	25	50	75	90
% τ above/below avg. from V.S.	22%	1.6%	30.1%	--	31.7%	3.2%	14.3%	12.7%	3.2%	19%	16%	12.7%	12.7%	6.3%	14.3%	12.7%	6.3%	22%

CORRECTED VALUES DUE TO NORMALIZATION OF VANE SHEAR STRENGTH TEST DATA FROM TEST SET #1

TEST #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
% difference fm. V.S. avg	22%	1.6%	30.1%	-	31.7%	3.2%	14.3%	12.7%	3.2%	19%	16%	12.7%	12.7%	6.3%	14.3%	12.7%	6.3%	22%
CORRECTED (psi) values for σ_1	65.4	115.8	36.8	-	106.1	59.4	67.1	75.6	81.8	41.8	13.4	33.1	90.4	102.5	42.0	60.9	83.4	120.8
TOTAL (psi) stress (σ_3)	50	50	25	-	75	50	50	50	75	25	10	25	75	90	25	50	75	90
Corrected deviator stress(psi)	15.4	65.8	11.8	-	31.1	9.4	17.1	25.6	6.8	16.8	3.4	8.1	15.4	12.5	17.0	10.9	8.4	30.8
time of (min) triaxial test	60	600	180	-	540	120	45	120	45	45	45	45	45	45	45	45	45	45
PEAK PORE pressure (psi)	6.24	7.11	3.0	-	18.3	-	6.0	7.32	10.3	7.12	2.3	8.45	6.76	6.31	2.3	3.64	10.63	9.76
Effective horiz. stress (psi)	43.8	42.9	21.0	-	56.7	-	44.0	42.7	64.7	17.8	7.7	16.5	68.2	83.7	22.7	46.4	64.4	80.2
Effective vertical stress (psi)	59.2	108.7	14.8	-	87.8	-	61.1	68.3	71.5	34.7	11.1	24.7	83.6	96.2	39.7	57.3	72.8	111.0

Data #: Set	2 Before	2 After	3 Before	3 After	4 Before	4 After	5 Before	5 After	6 Before	6 After	7 Before	7 After	8 Before	8 After	9 Before	9 After	10 Before
wt. (g) paper	.35	.7	.6	.5			.5	.8	.7	.6	.5	.5	.7	.8	.8	.8	.9
wt. paper & wet soil	60.87	103.6	30.50	47.3			41.3	90.0	90.3	67.8	118.6	105.0	62.3	114.5	120.5	101.0	26.8
wt. paper & dry soil	50.40	83.2	22.8	37.0			29.4	68.9	68.0	54.9	90.7	76.6	45.7	88.9	87.6	74.1	19.1
wt. water	10.47	20.4	7.7	10.3			11.9	22.1	22.3	12.9	27.9	28.4	16.6	25.6	32.9	26.9	7.7
~~wet~~ dry soil	50.05	82.5	22.2	36.5			28.9	68.1	67.3	54.3	62.8	76.1	45.0	88.1	86.8	73.3	18.2
water content	.291	.250	.347	.282			.412	.324	.331	.237	.444	.373	.369	.290	.379	.366	.423

sample failure prior to testing

WATER CONTENT ANALYSIS FOR EACH SAMPLE BOTH PRIOR TO AND FOLLOWING TRIAXIAL TEST. FOR DATA SET #1

[Note: No water content analysis was performed on sample #1]

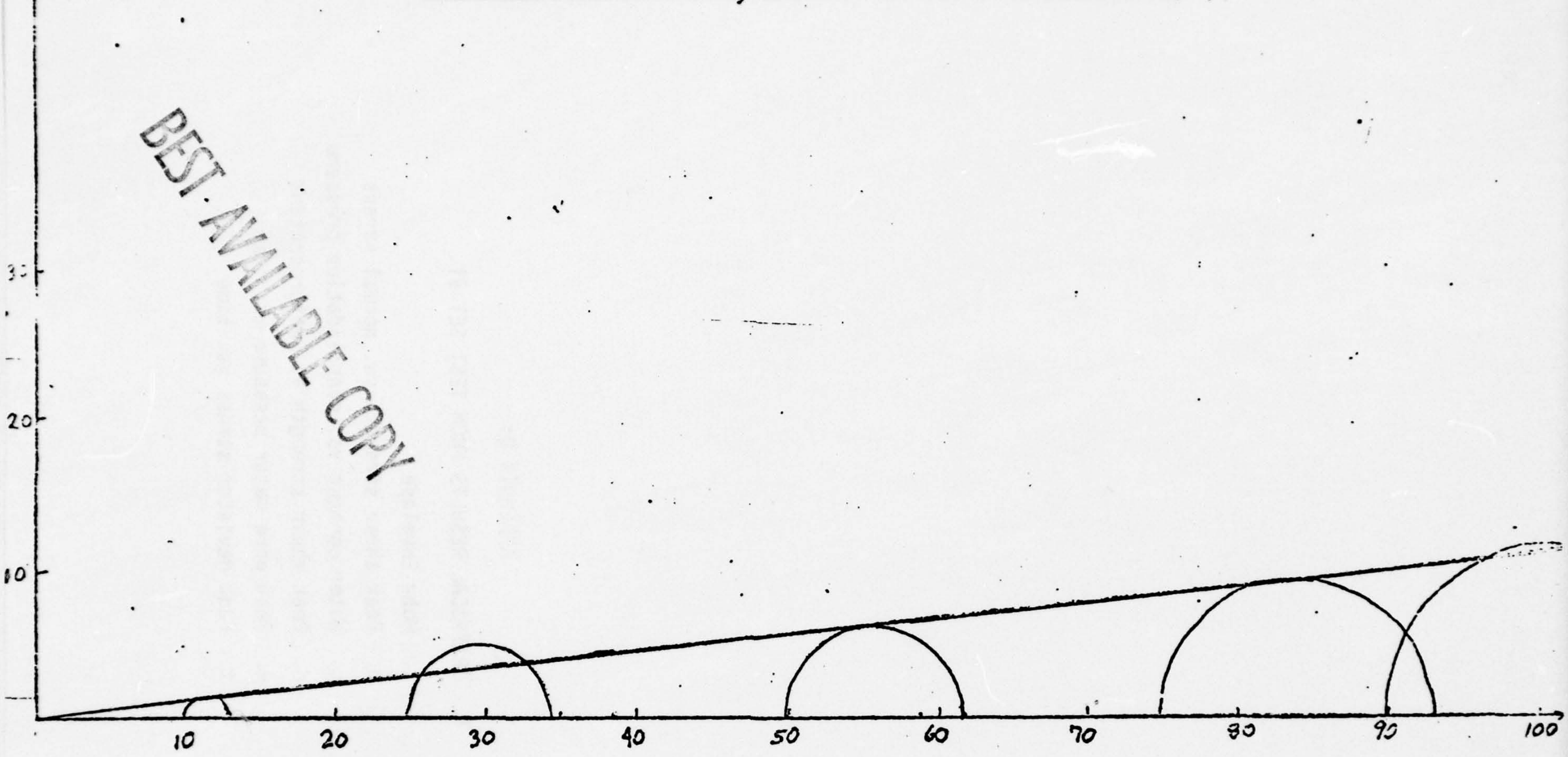
	10 After	11 Before	11 After	12 Before	12 After	13 Before	13 After	14 Before	14 After	15 Before	15 After	16 Before	16 After	17 Before	17 After	18 Before	18 After
wt. paper	.9	.7	.9	.8	.5	1.0	.9	1.0	.9	.6	.6	1.0	.9	.8	1.0	.9	1.0
wt. paper & wet soil	110.0	53.9	77.9	106.8	66.6	49.2	38.3	63.1	99.3	72.5	102.0	102.5	66.0	14.0	93.2	70.3	62.1
wt. paper & dry soil	87.0	40.9	58.9	79.4	49.7	35.7	28.3	44.8	77.8	52.4	80.0	72.7	49.7	10.0	73.6	56.7	54.4
wt. water	23.0	13.0	19.0	27.4	16.9	14.5	10.0	18.3	21.5	20.1	22.0	29.8	16.3	4.0	19.6	13.6	7.7
wt. dry soil	86.3	40.2	57.0	78.6	49.2	34.7	27.4	43.8	76.9	51.8	79.4	81.7	98.8	9.2	72.6	55.8	53.4
water content	.266	.323	.333	.349	.343	.418	.365	.417	.279	.388	.277	.364	.334	.434	.270	.244	.144

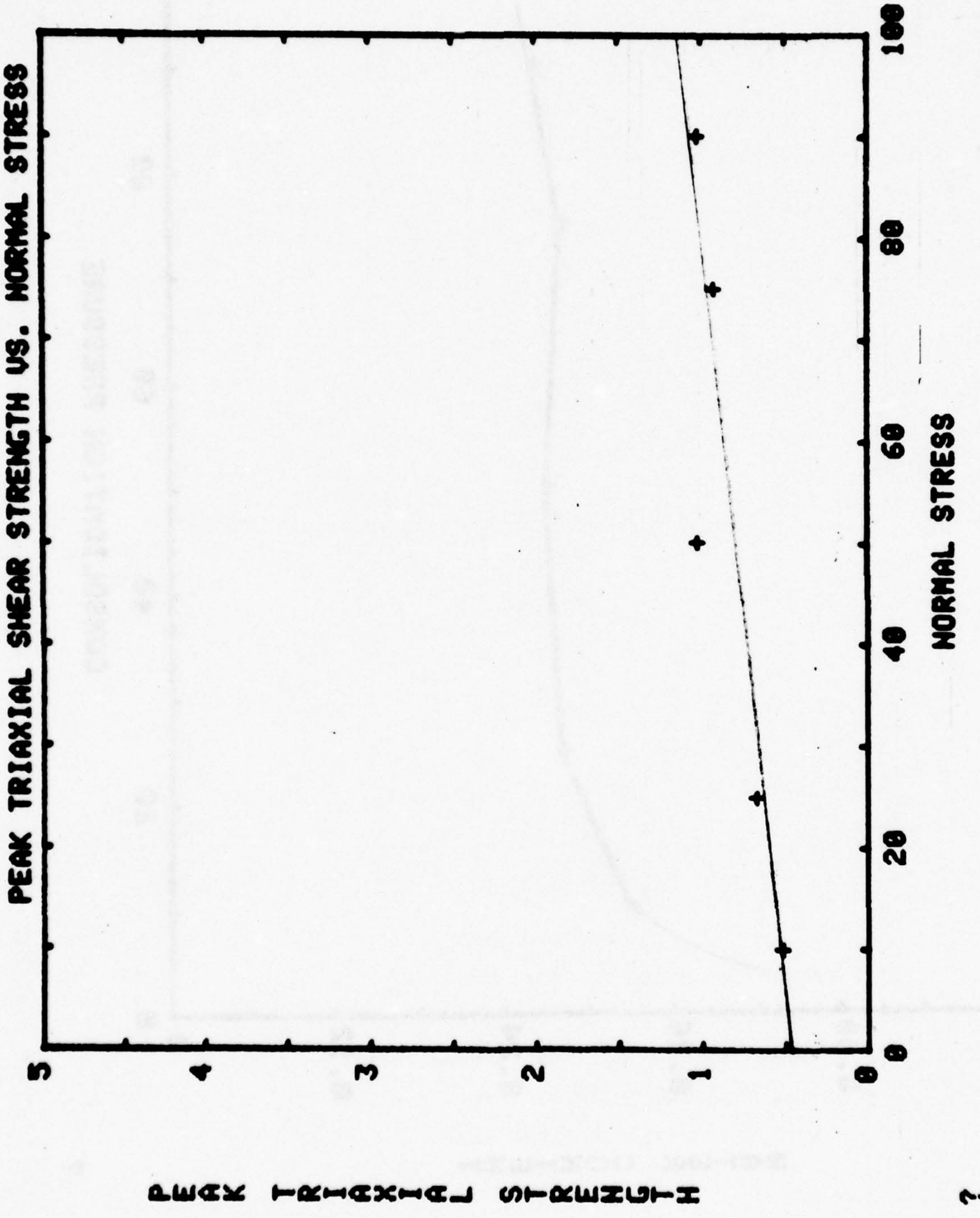
APPENDIX D:

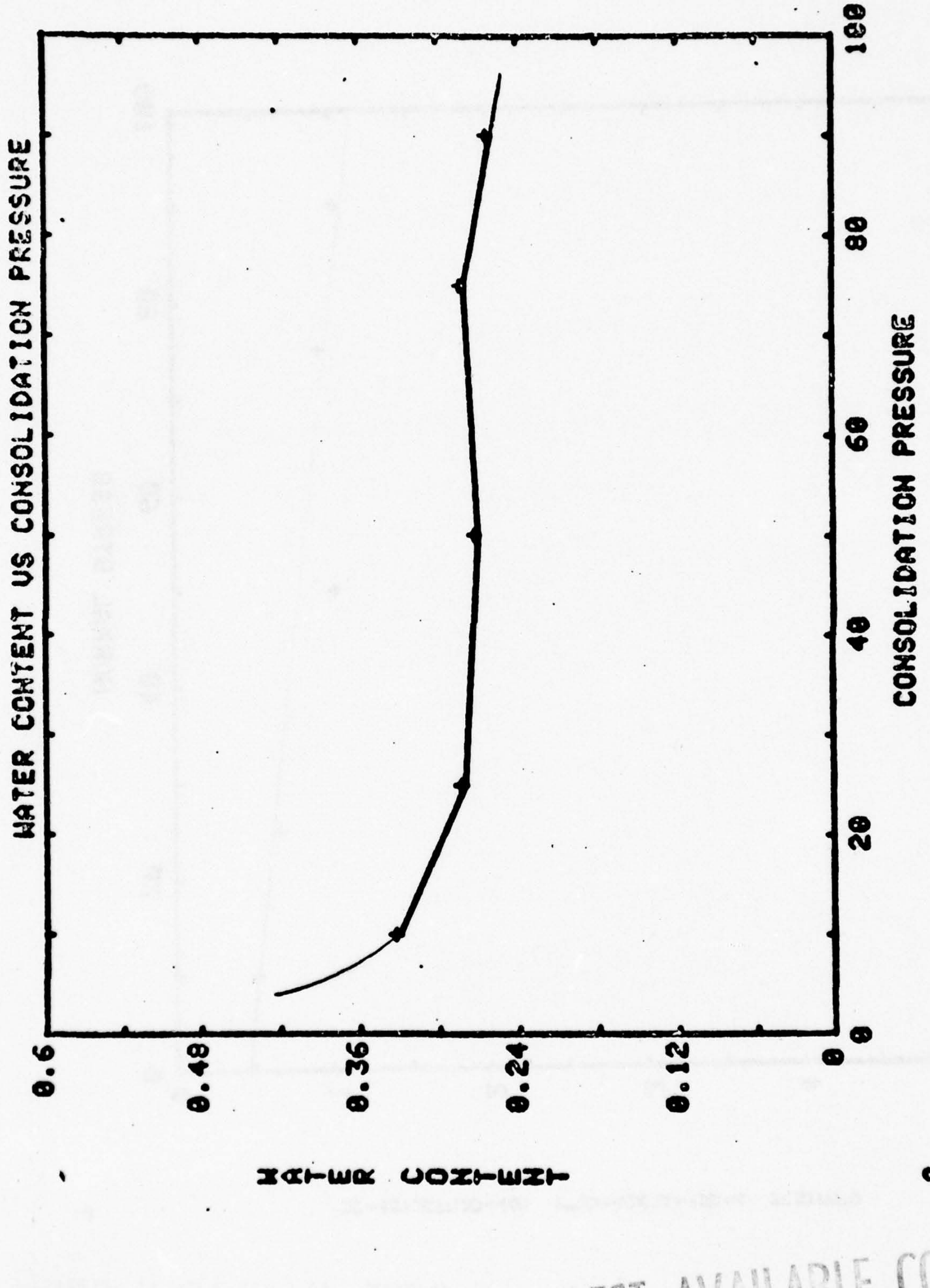
1. GRAPHICAL RESULTS FROM TEST SET #1

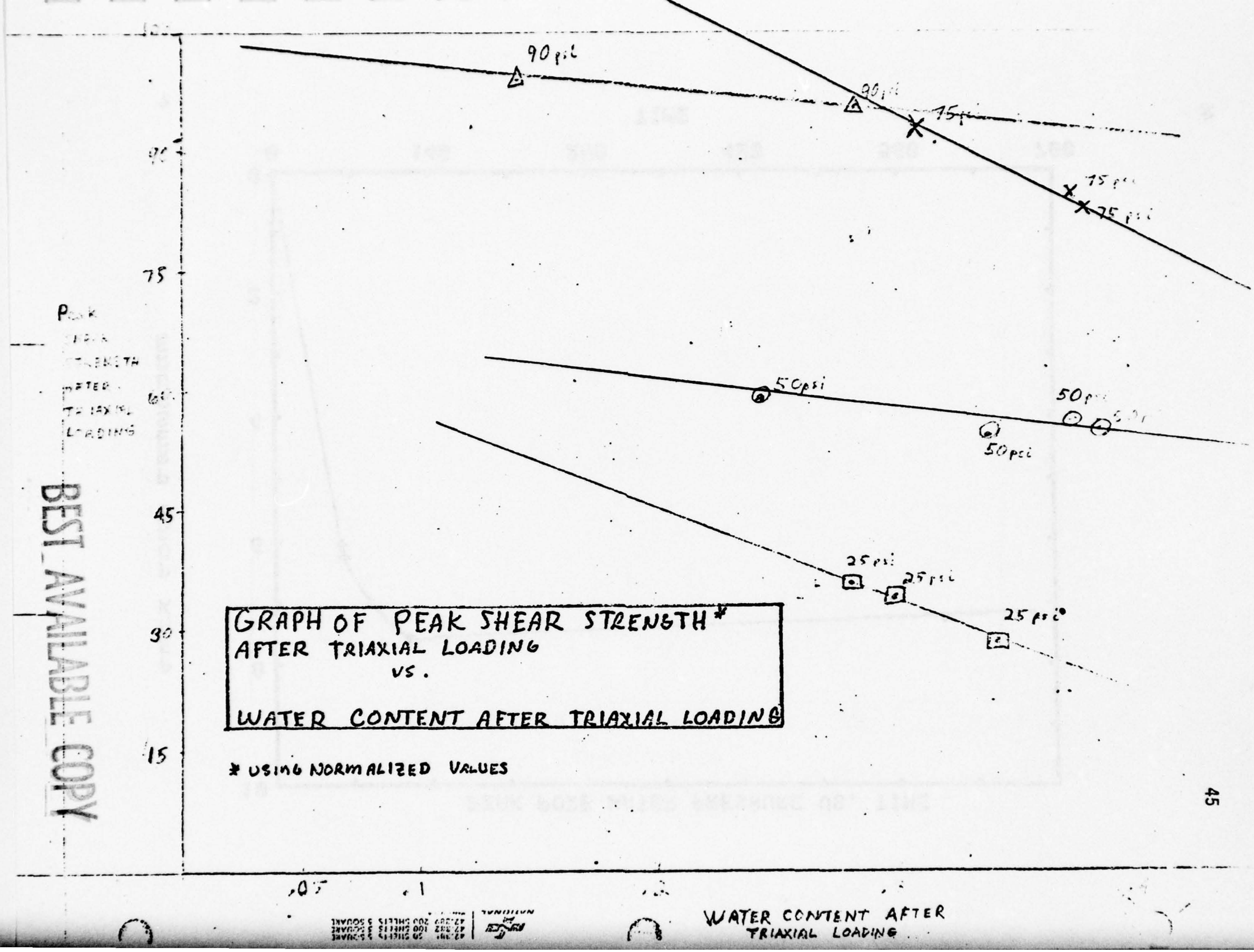
   a. Mohr Envelope
   b. Peak shear strength vs. normal stress
   c. Water content vs. consolidation pressure
   d. Peak shear strength vs. water content
   e. Peak pore water pressure vs. time
   f. Peak deviator stress vs. time

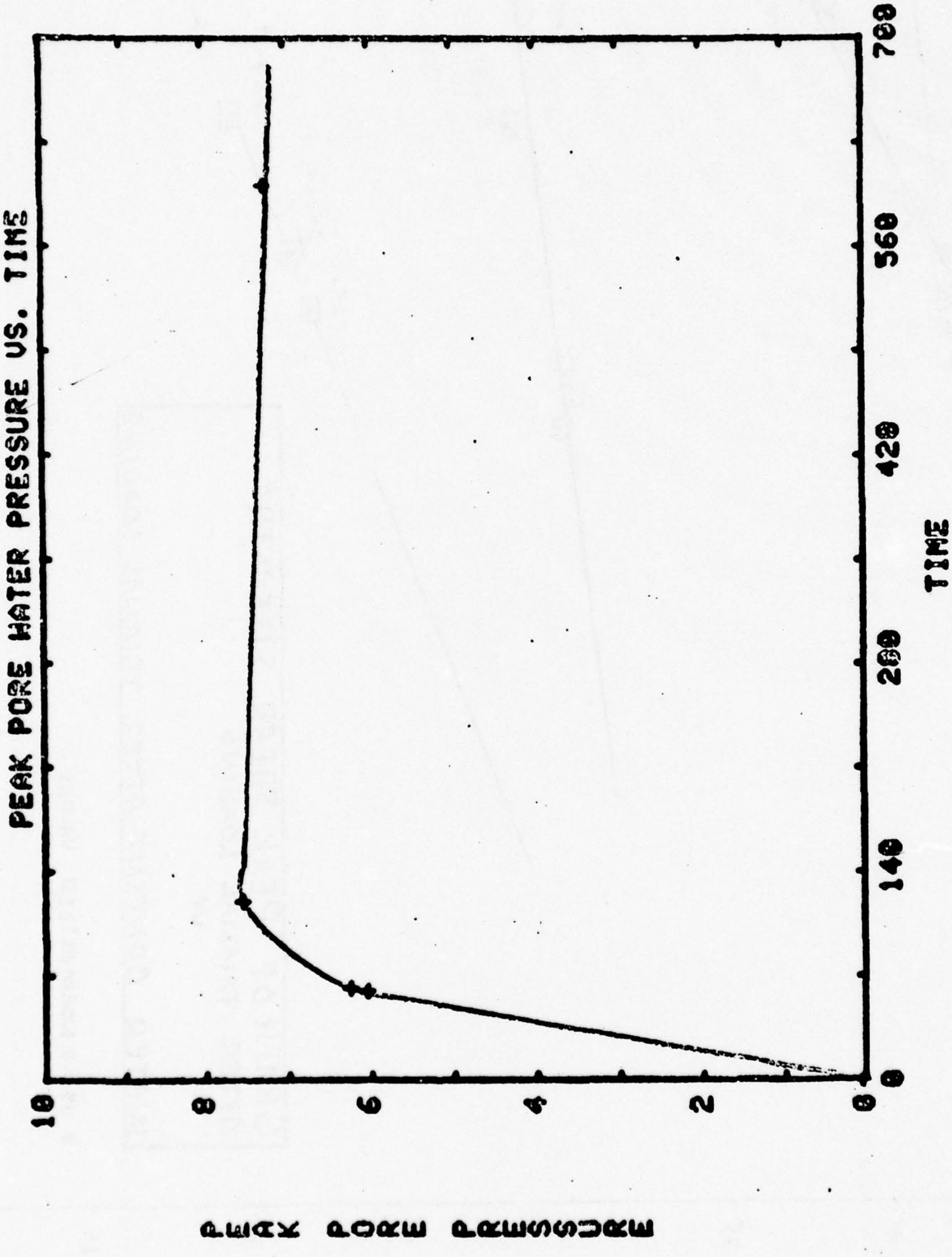
MOHR ENVELOPE FOR ALL TESTS @ 10, 25, 50, 75, 90 psi
TOTAL STRESSES, NORMALIZED VALUES

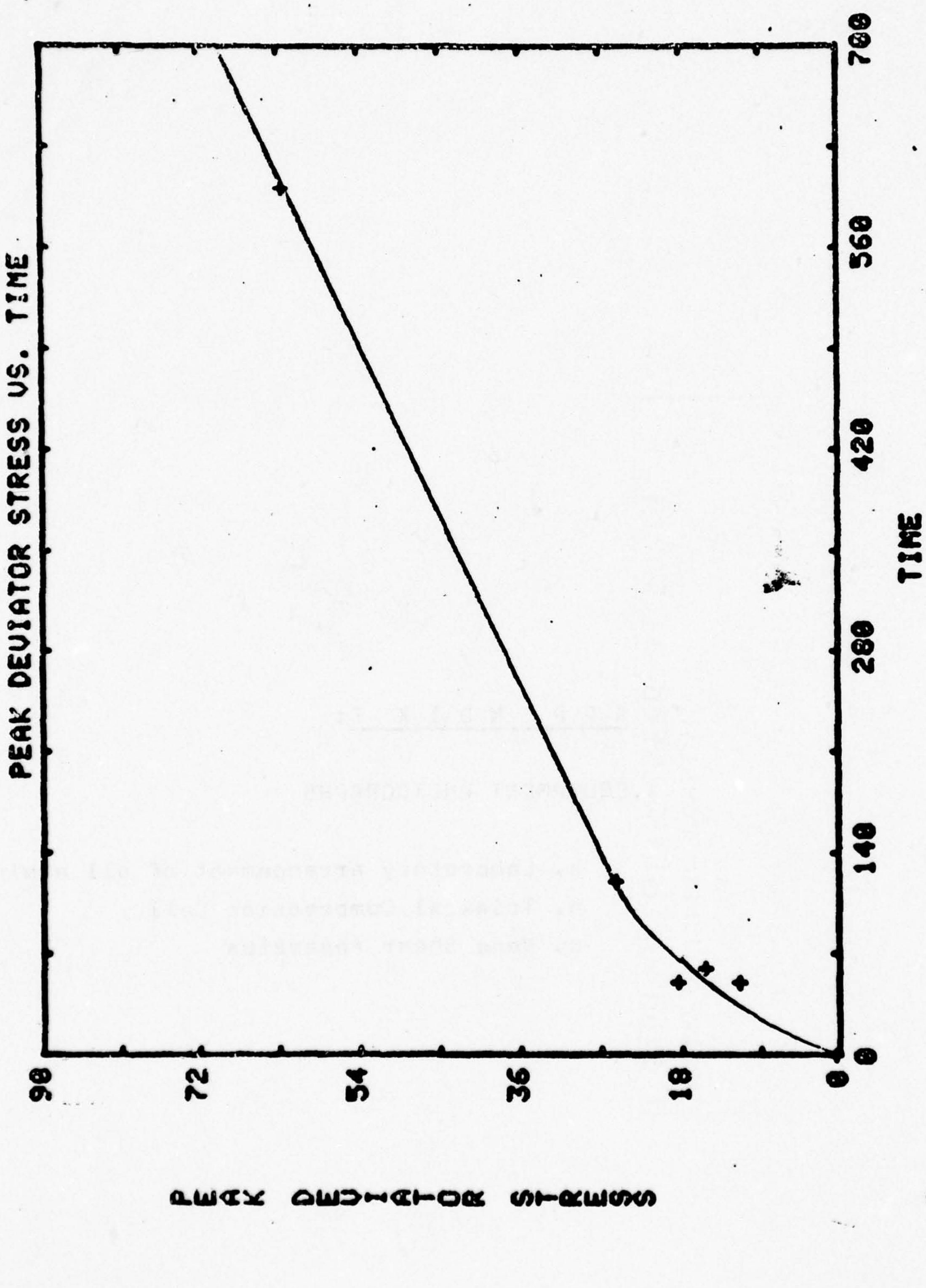



PEAK TRIAXIAL SHEAR STRENGTH VS. NORMAL STRESS
NORMAL STRESS
PEAK TRIAXIAL STRENGTH
0
20
40
60
80
100
0
1
2
3
4
5


WATER CONTENT VS CONSOLIDATION PRESSURE
WATER CONTENT
0.6
0.48
0.36
0.24
0.12
0
CONSOLIDATION PRESSURE
0
20
40
60
80
100


GRAPH OF PEAK SHEAR STRENGTH*
AFTER TRIAXIAL LOADING
VS.
WATER CONTENT AFTER TRIAXIAL LOADING
* USING NORMALIZED VALUES
PEAK SHEAR STRENGTH AFTER TRIAXIAL LOADING
WATER CONTENT AFTER TRIAXIAL LOADING
90 psi
75 psi
50 psi
25 psi
75
60
45
30
15
.05
.1


PEAK PORE WATER PRESSURE VS. TIME
PEAK PORE PRESSURE
TIME
0
140
280
420
560
700
0
2
4
6
8
10


PEAK DEVIATOR STRESS VS. TIME
PEAK DEVIATOR STRESS
TIME
0
18
36
54
72
90
0
140
280
420
560
700

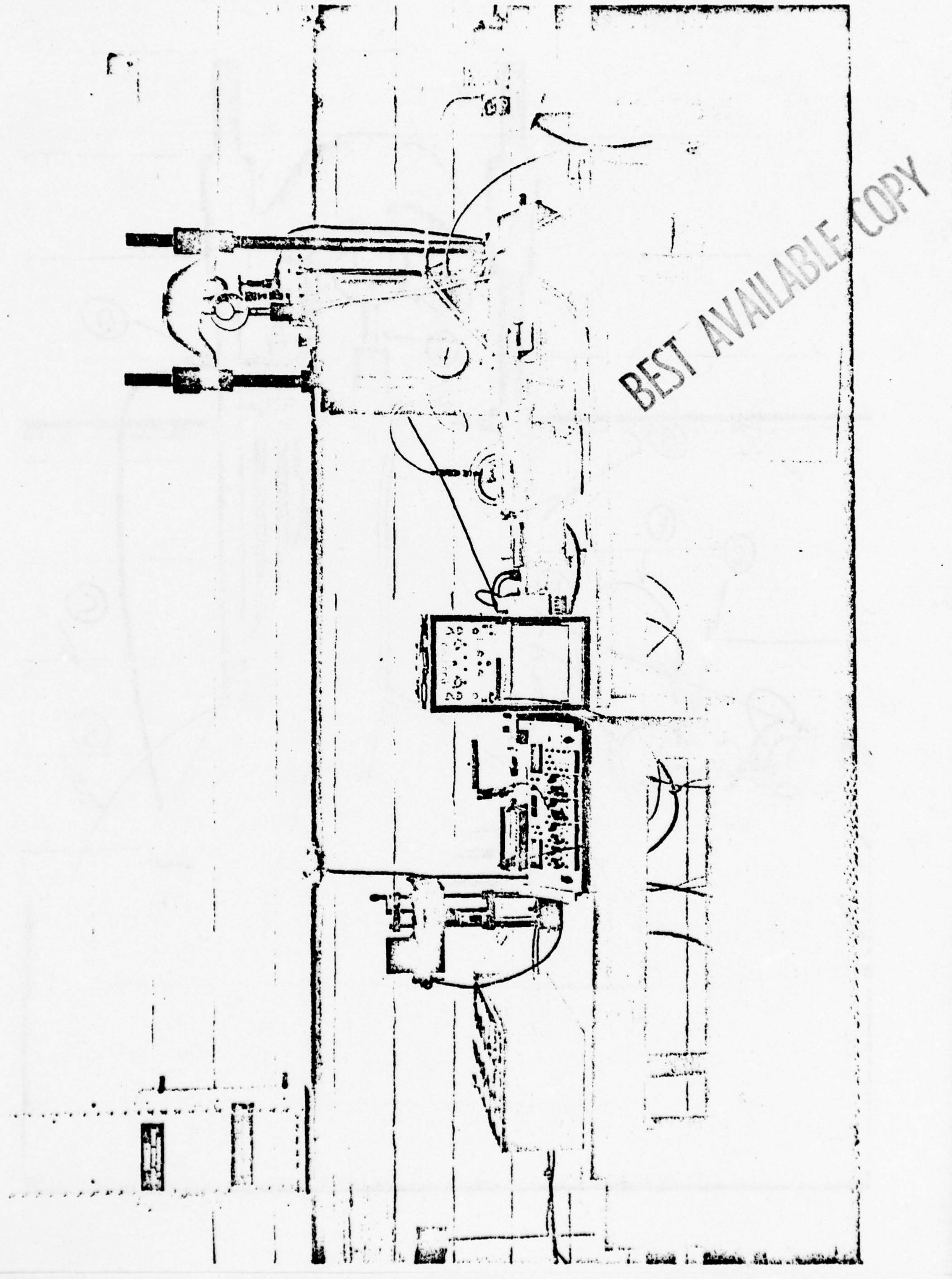
APPENDIX E:

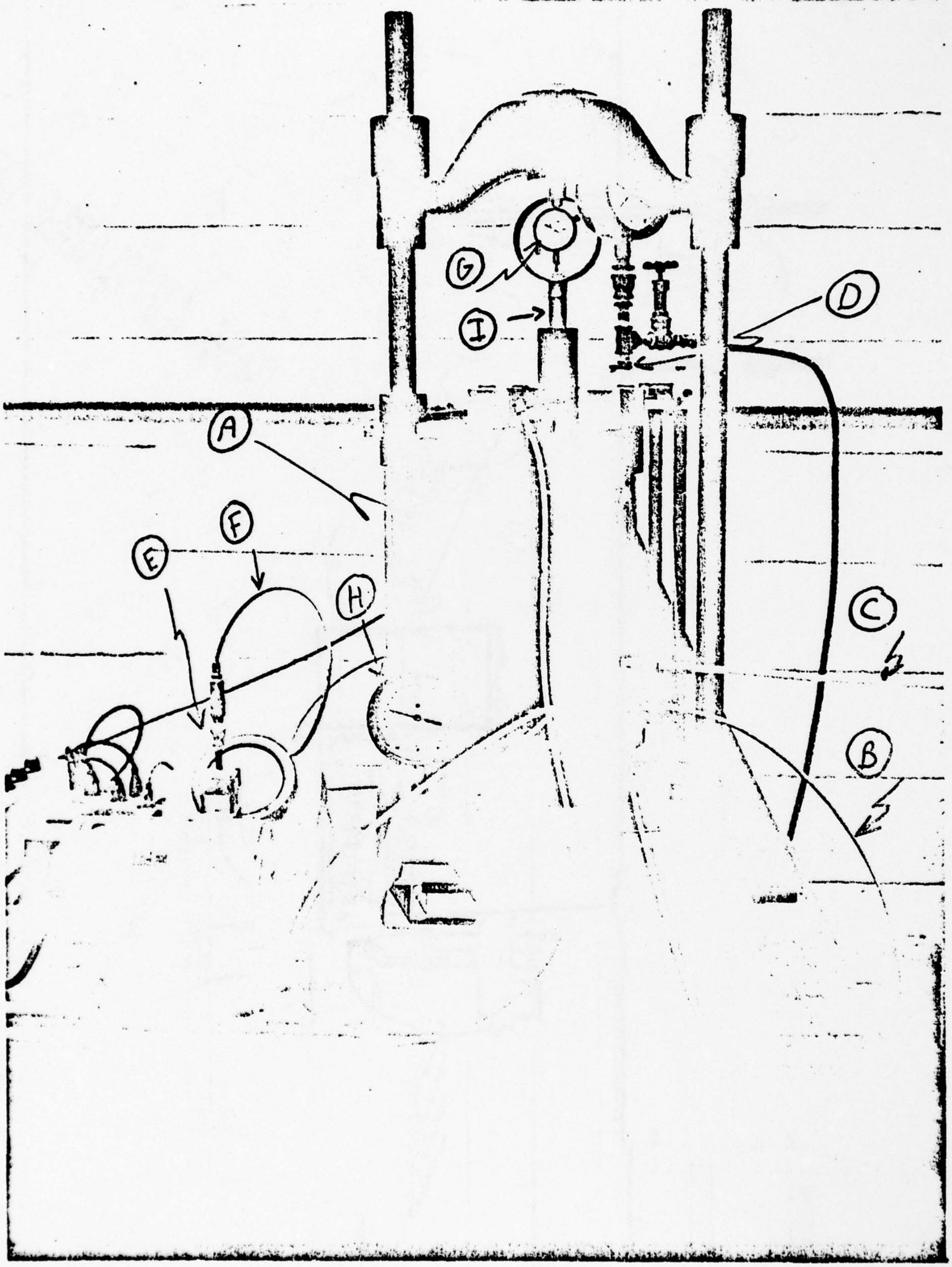
1.EQUIPMENT PHOTOGRAPHS

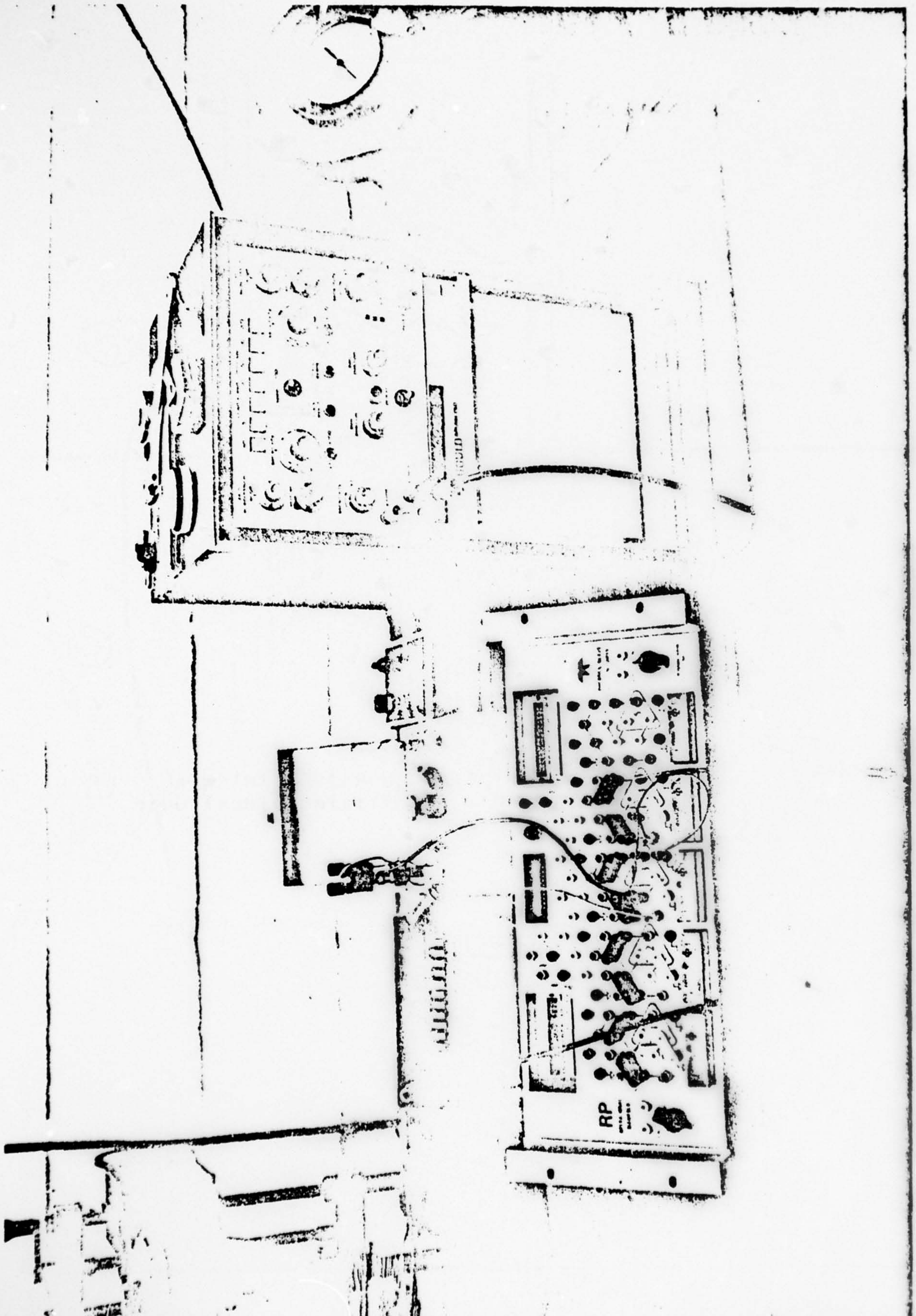
a. Laboratory arrangement of all equipment

b. Triaxial Compression Cell

c. Vane Shear Apparatus




G
I
D
A
F
E
H
C
B


RP

APPENDIX F:

1. CONSOLIDATED UNDRAINED TRIAXIAL TEST DATA SET #1: Individual data

CONSOLIDATED UNDRAINED TRIAXIAL TEST #1 DATA

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0017	7.56	1.02	.135	1.5	.5
10	.0022	9.79	1.65	.270	3.0	1.0
15	.0026	11.79	1.98	.405	4.5	1.5
20	.0029	13.0	2.19	.54	6.0	2.0
25	.0032	14.24	2.39	.675	7.5	2.5
30	.0034	15.22	2.56	.810	9.0	3.0
35	.0037	16.47	2.78	.945	10.5	3.5
40	.0039	17.35	2.92	1.08	12.0	4.0
45	.0041	18.24	3.07	1.22	13.5	4.5
50	.0043	18.91	3.18	1.35	15.0	5.0
55	.0046	20.47	3.45	1.48	16.5	6.5
60	.0048	21.40	3.59	1.62	18.0	8.0

Lateral Pressure = 50 psi

h_o = 8.0" h_f = 6.38"

CONSOLIDATED UNDRAINED TRIAXIAL TEST #2 DATA

Time (hr)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	.0	0	0	0	0	0
.5	.0015	5.12	.86	.05	.92	0
1.0	.0092	4.09	.69	.11	1.85	.2
1.5	.0123	5.574	.92	.16	2.78	.5
2.0	.0176	7.83	1.32	.22	3.70	.5
2.5	.0211	9.389	1.58	.28	4.58	.6
3.0	.0240	10.68	1.80	.33	5.55	.7
3.5	.0265	11.792	1.98	.38	6.47	.8
4.0	.0309	13.75	2.31	.44	7.40	.9
4.5	.0343	15.262	2.57	.50	8.32	1.0
5.0	.0395	17.578	2.96	.55	9.25	1.2
5.5	.0432	19.224	3.23	.61	10.17	1.3
6.0	.0481	21.40	3.60	.66	11.1	1.5
6.5	.0534	23.763	4.00	.72	12.02	2.0
7.0	.0578	25.721	4.33	.78	12.95	2.5
7.5	.0609	27.100	4.56	.83	13.87	3.5
8.0	.0748	33.286	5.60	.89	14.80	4.5
8.5	.0768	34.176	5.754	.94	15.72	5.0
9.0	.0835	37.157	6.25	1.00	16.65	5.5
9.5	.0872	38.804	6.53	1.05	17.58	6.0
10.0	.0896	39.87	6.71	1.11	18.52	6.5
10.5	.0904	40.23	6.77	1.16	19.42	7.0

Lateral Pressure = 50 psi

h_o = 8.0" h_f = 6.84"

CONSOLIDATED UNDRAINED TRIAXIAL TEST #5 DATA

Time (hr)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
.5	.0011	4.76	.80	.12	1.5	.5
1.0	.0177	7.87	1.33	.24	3.0	1.0
1.5	.0209	9.30	1.56	.36	4.5	1.5
2.0	.0249	11.08	1.86	.48	6.0	2.0
2.5	.0288	12.81	2.15	.6	7.5	2.5
3.0	.0327	14.55	2.45	.72	9.0	3.5
3.5	.0360	16.02	2.70	.84	10.5	5.0
4.0	.0374	16.64	2.80	.96	12.0	6.5
4.5	.0383	17.04	2.87	1.08	13.5	8.0
5.0	.0393	17.49	2.94	1.2	15.0	9.0
5.5	.0400	17.80	2.99	1.32	16.5	10.0
6.0	.0407	18.11	3.05	1.44	18.0	11.0
6.5	.0415	18.47	3.11	1.56	19.5	12.0
7.0	.0422	18.78	3.16	1.68	21.0	14.0
7.5	.0428	19.05	3.20	1.80	22.5	15.5
8.0	.0434	19.31	3.25	1.92	24.0	17.0
8.5	.0440	19.58	3.50	2.04	25.5	18.0
9.0	.0449	19.87	3.57	2.16	27.0	20.0

Lateral Pressure = 75 psi

h_o = 8" h_f = 5.84"

Cut Test Data #6

(Note: CUT = Consolidated Undrained Triaxial)

h_o = 6.5" Δh = 2.25" P_{lot} = 50 psi

h_f = 4.25

Time	Stress Gage Reading (in)	Axial Load (lb)	Axial Stress (psi)	Strain Reading (in)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
15 min	.0024	10.68	1.8	.281	4.32	0
30 min	Gage Jammed	-	-	.562	8.65	0
45 min	.0082	36.49	6.14	.844	12.95	0
1 hr	.0098	43.61	7.34	1.125	17.31	0
1 hr 15 min	.0102	45.40	7.65	1.406	21.63	0
1 hr 30 min	.0104	46.28	7.79	1.6875	25.91	0
1 hr 45 min	.0106	47.17	7.94	1.969	30.1	0
2 hrs	.0108	48.06	8.09	2.25	34.6	0

Original strain rate to obtain 23% final strain was tried, but the strain fluctuated to such a great extent that the final height of sample was measured to determine the average strain rate over the testing period. Our strain rate motor is of insufficient sensitivity to get an accurate strain rate ahead of time.

The thrust rod had no more clearance after 2 hrs of testing, so the test ceased after 2 hrs.

DATA IS INVALID AS PORE PRESSURE READINGS FAILED TO REGISTER VANE SHEAR TEST DATA ON SAMPLE FOLLOWING TRIAXIAL TEST

90°/min shear rate

Peak shear strength = .85 psi

remoulded shear strength = .3 psi

CUT TEST DATA #7

h_o = 6.5"　　$P_{lateral}$ = 50 psi

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0116	51.62	8.7	.165	2.5	.2
10	.0220	97.9	16.48	.33	5.08	.7
15	.0223	99.2	16.71	.495	7.61	1.1
20	.0224	99.7	16.80	.66	10.15	1.8
25	.0225	100.12	16.85	.825	12.7	2.5
30	.0226	101.5	16.93	.99	15.23	3.5
35	.0228	101.4	17.08	1.155	17.7	5.0
40	.0229	101.9	17.15	1.32	20.31	7.0
45	.0231	102.8	17.31	1.5	23.0	9.5

Strain Rate = .033 in/min

Vane shear test immediately following
Triaxial Test:

Results: Peak strength = 1.0 psi
Remoulded strength = .5 psi

CUT TEST DATA #8

h_o = 6.5" P_{lat} = 50 psi

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
15	.00625	27.81	4.68	.1875	2.88	.5
30	.0089	39.6	6.67	.375	5.77	1.0
45	.0114	50.73	8.54	.5625	8.657	2.5
60	.0135	60.87	10.11	.75	11.54	3.5
75	.0170	75.65	12.74	.9375	14.42	4.5
90	.0188	88.11	14.83	1.125	17.31	5.5
105	.0229	101.95	17.16	1.3125	20.197	6.5
120	.0258	114.81	19.33	1.50	23.01	8.8

Vane Test: on Sample   Peak Strength = 1.1 psi

Remoulded Strength = .35 psi

CUT TEST DATA #9

h_o = 6.5" P_{lat} = 75 psi   Strain Rate = .00825 in/15 sec

h_f = 5.0"   = .033 in/min

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0012	5.34	.899	.165	2.5	0.5
10	.0022	9.79	1.648	.33	5.08	1.0
15	.0026	11.57	1.948	.495	7.61	1.5
20	.0027	12.015	2.023	.66	10.15	2.5
25	.0030	13.35	2.248	.825	12.7	4.5
30	.0034	15.13	2.548	.99	15.23	6.5
35	.0052	23.14	3.896	1.155	17.7	8.0
40	.0058	25.81	4.346	1.32	20.31	10.0
45	.0064	28.48	4.795	1.5	23.0	12.0

Vane Test on failed sample:

Peak τ = 1.1 psi

Remoulded τ = .7 psi

CUT TEST DATA #10

$h_o = 6.5"$ $P_{lat} = 25$ psi Strain Rate = .033 in/min

$h_f = 5.0"$

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0032	14.24	2.4	.165	2.5	.5
10	.0047	20.915	3.52	.33	5.08	1.0
15	.0058	25.81	4.35	.495	7.61	1.5
20	.00685	30.48	5.132	.68	10.15	2.0
25	.00785	34.93	5.88	.825	12.7	3.2
30	.0089	39.6	6.67	.99	15.23	4.5
35	.0104	46.28	7.79	1.155	17.76	5.0
40	.0135	60.07	10.11	1.32	20.3	6.0
45	.0152	67.64	11.39	1.5	23.0	7.0

Vane Test on failed sample:

Peak τ = .95 psi
Remoulded τ = .25 psi

CUT TEST DATA #11

P_{lat} = 10 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0006	2.67	.45	.165	2.5	.5
10	.0009	4.005	.674	.33	5.08	1.0
15	.0011	4.895	.824	.495	7.61	1.0
20	.0013	5.785	.974	.68	10.15	1.5
25	.0014	6.23	1.05	.825	12.7	1.6
30	.0016	7.12	1.198	.99	15.23	2.0
35	.0017	7.565	1.27	1.155	17.76	2.0
40	.00185	8.23	1.386	1.32	20.3	2.0
45	.0020	8.90	1.498	1.5	23.0	2.0

Vane Shear Test

Peak τ = .45 psi
Remoulded τ = .25 psi

CUT TEST DATA #12

P_{lat} = 25 psi

h_o = 6.5

h_f = 5.0

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Stress (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0007	3.115	.524	.165	2.5	.5
10	.0022	9.79	1.64	.33	5.08	1.5
15	.0032	14.24	2.4	.495	7.61	2.0
20	.0033	14.68	2.47	.68	10.15	3.0
25	.0037	16.465	2.77	.825	12.7	4.0
30	.0041	18.245	3.07	.99	15.23	5.0
35	.0055	24.475	4.12	1.155	17.76	6.5
40	.0059	26.255	4.42	1.32	20.3	7.5
45	.0065	28.925	4.87	1.50	23.0	8.5

Sample shear strength low due to partial bulging before start of test

Vane Shear Test:
Peak τ = .55 psi
Remoulded τ = .2 psi

CUT TEST DATA #13

P_{lat} = 75 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0099	4.005	.674	.165	2.5	.5
10	.0016	7.12	1.199	.33	5.08	1.0
15	.0021	9.345	1.573	.495	7.61	1.5
20	.0028	12.46	2.098	.68	10.15	2.0
25	.0037	16.465	2.772	.825	12.7	3.0
30	.0042	18.69	3.147	.99	15.23	4.0
35	.0062	27.59	4.645	1.155	17.76	5.0
40	.0069	30.705	5.170	1.32	20.3	6.0
45	.0073	32.485	5.470	1.50	23.0	7.0

Vane Shear Test
Peak τ = 1.3 psi
Remoulded τ = .7 psi

CUT TEST DATA #14

$P_{lateral}$ = 90 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0050	22.25	3.746	.165	2.5	1.0
10	.0076	33.82	5.694	.33	5.08	2.0
15	.0098	43.61	7.342	.495	7.61	3.0
20	.0121	53.845	9.066	.68	10.15	3.5
25	.0142	63.19	10.64	.825	12.7	4.0
30	.0166	73.87	12.438	.99	15.23	4.5
35	.0192	85.44	14.386	1.155	17.76	5.0
40	.0219	97.455	16.41	1.32	20.3	5.0
45	.0250	111.25	18.73	1.50	23.0	5.5

Vane Shear Test
Peak τ = 5.0 psi
Remoulded τ = .45 psi

CUT TEST DATA #15

$P_{lateral}$ = 25 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0150	66.75	11.24	.165	2.5	.5
10	.0192	85.44	14.38	.33	5.08	.5
15	.0222	98.79	16.63	.495	7.61	.8
20	.0244	108.58	18.28	.68	10.15	1.0
25	.0266	118.37	19.93	.825	12.7	1.0
30	.0281	125.045	21.05	.99	15.23	1.25
35	.0300	133.5	22.47	1.155	17.76	1.5
40	.0320	142.4	23.98	1.32	20.3	2.0
45	.0340	151.3	25.47	1.5	23.0	2.0

Vane Shear Test
   Peak τ = .8 psi
   Remoulded τ = .35 psi

CUT TEST DATA #16

$P_{lateral}$ = 50 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0030	13.35	2.25	.165	2.5	0
10	.0037	16.465	2.77	.33	5.08	.5
15	.0041	18.245	3.072	.495	7.61	1.0
20	.0043	10.135	3.22	.68	10.15	1.0
25	.0045	20.025	3.37	.825	12.7	1.5
30	.0047	20.915	3.52	.99	15.23	2.0
35	.0049	21.805	3.67	1.155	17.76	2.5
40	.0053	23.585	3.97	1.32	20.3	3.0
45	.0058	25.81	4.35	1.5	23.0	3.5

Vane Shear Test after TCC failure

Peak τ = 1.1 psi
Remoulded τ = .3 psi

CUT TEST DATA #17

$P_{lateral}$ = 75 psi

h_o = 6.5"

h_f = 5.0"

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0015	6.675	1.12	.165	2.5	1.0
10	.0019	8.455	1.42	.33	5.08	2.0
15	.0031	13.795	2.32	.495	7.61	3.0
20	.0041	18.245	3.07	.68	10.15	4.5
25	.0043	19.135	3.22	.825	12.7	6.0
30	.0044	19.58	3.297	.99	15.23	7.5
35	.0046	20.47	3.447	1.155	17.76	9.0
40	.0047	20.915	3.52	1.32	20.3	10.0
45	.0049	21.805	3.67	1.5	23.0	11.0

Vane Shear Test Results:

Peak τ = .85 psi
Remoulded τ = .5 psi

CUT TEST #18

$P_{lateral}$ = 90 psi

h_o = 6.5"

h_f = 5.0"

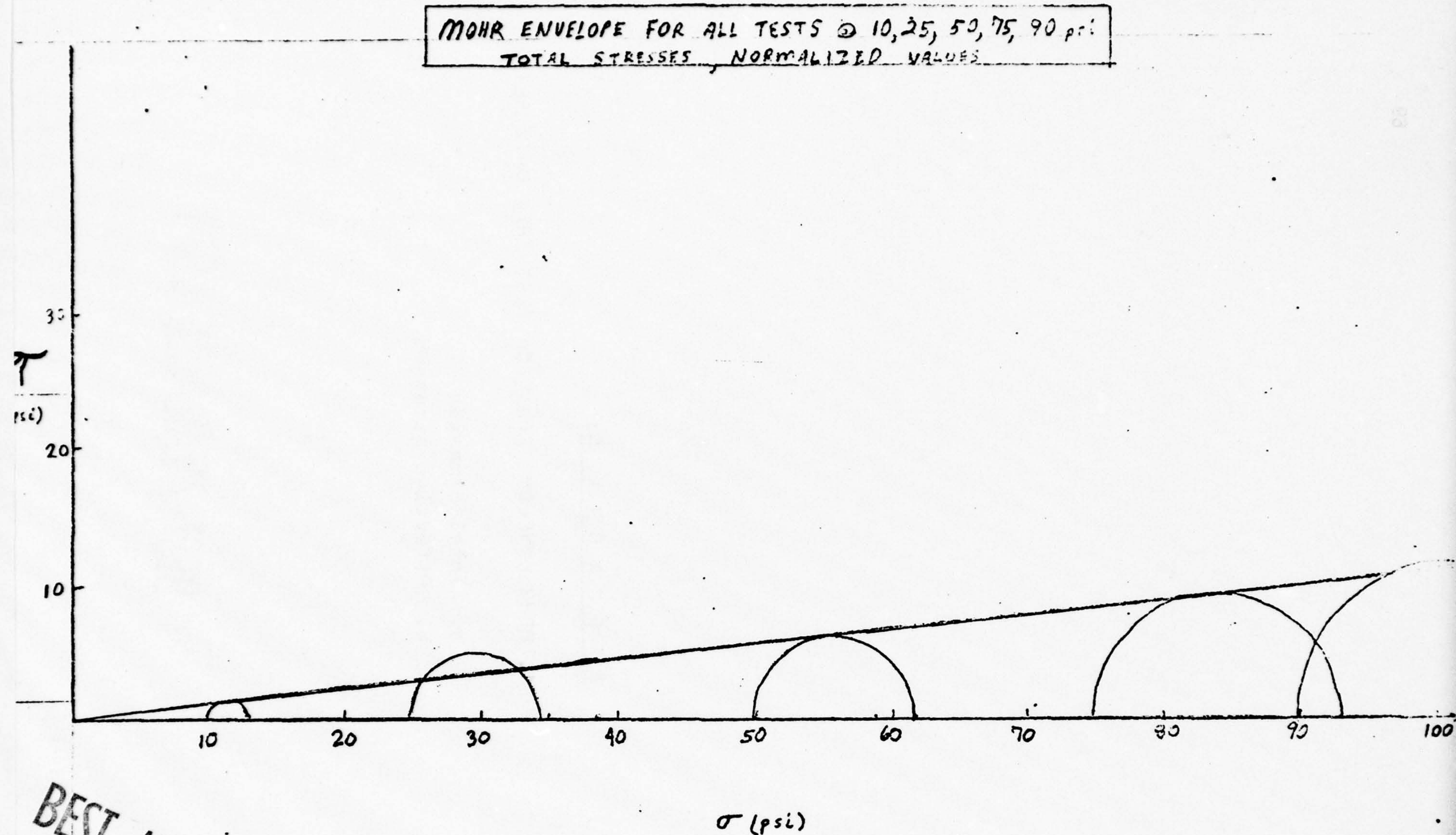
Time (min)	Stress Gage (in.)	Axial Load (in.)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0026	11.57	1.95	.165	2.5	.5
10	.0050	22.25	3.75	.33	5.08	1.0
15	.0043	19.135	3.22	.495	7.61	2.0
20	.0058	25.81	4.35	.68	10.15	3.5
25	.0075	33.375	5.62	.825	12.7	5.0
30	.0074	32.93	5.54	.99	15.23	6.0
35	.0094	41.83	7.04	1.155	17.76	7.0
40	.0118	52.51	8.84	1.32	20.3	8.0
45	.0126	56.07	9.44	1.5	23.0	9.5

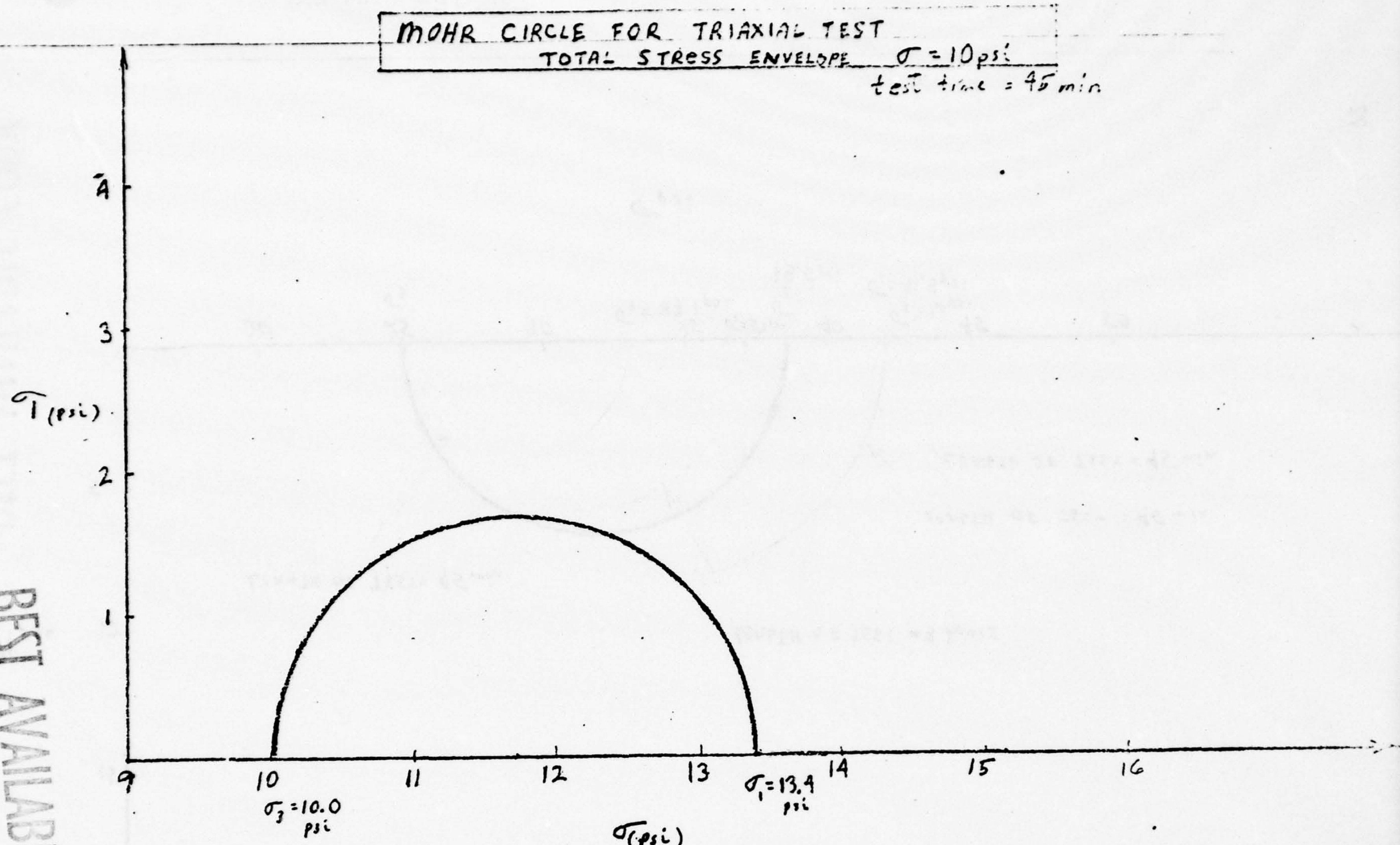
Vane Shear Test Results:
Peak τ = 2.8 psi
Remoulded τ = 1.4 psi

A P P E N D I X G:

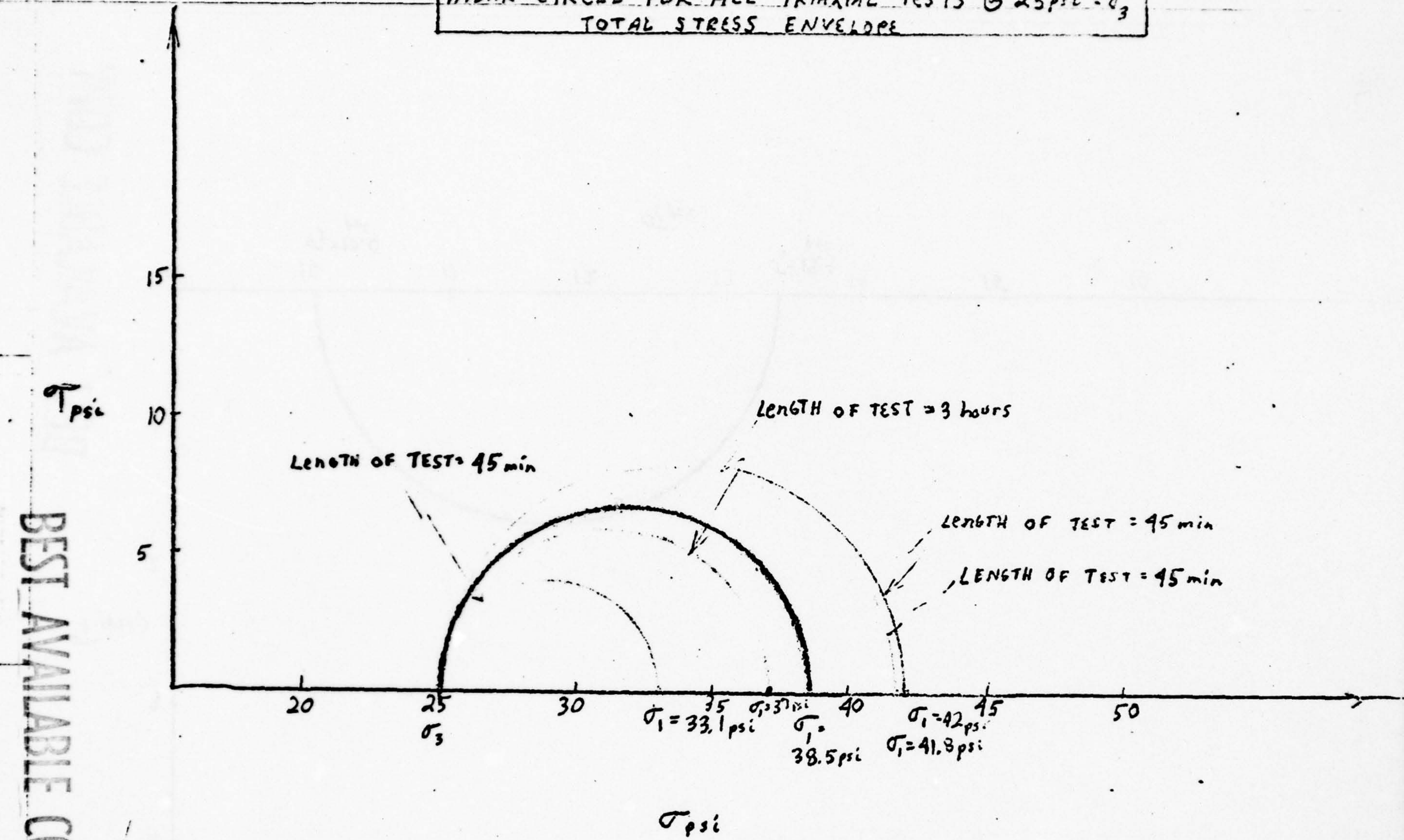
1. MOHR ENVELOPE FOR EACH TEST FROM DATA SET #1

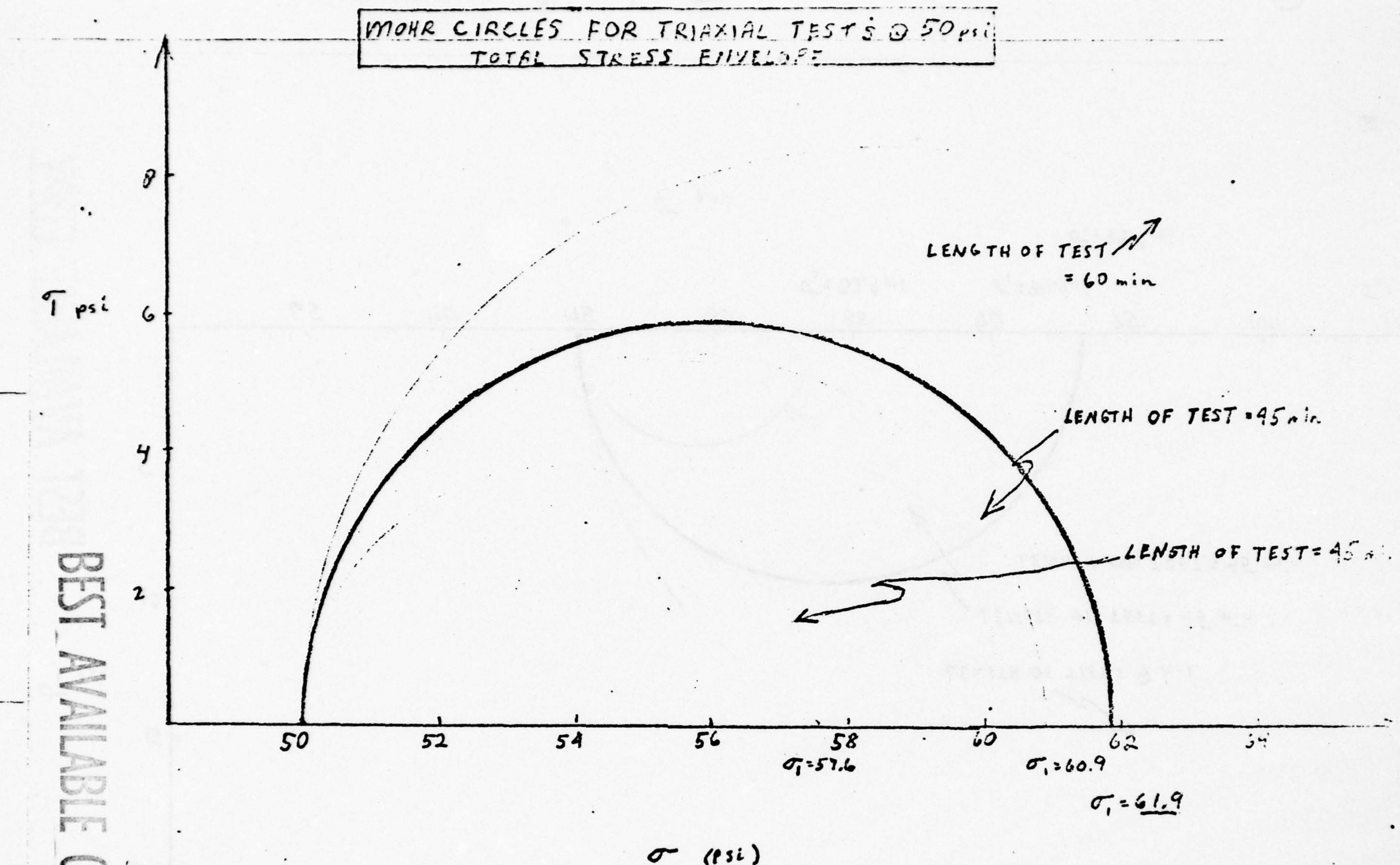
a. Total stresses
b. Effective stresses

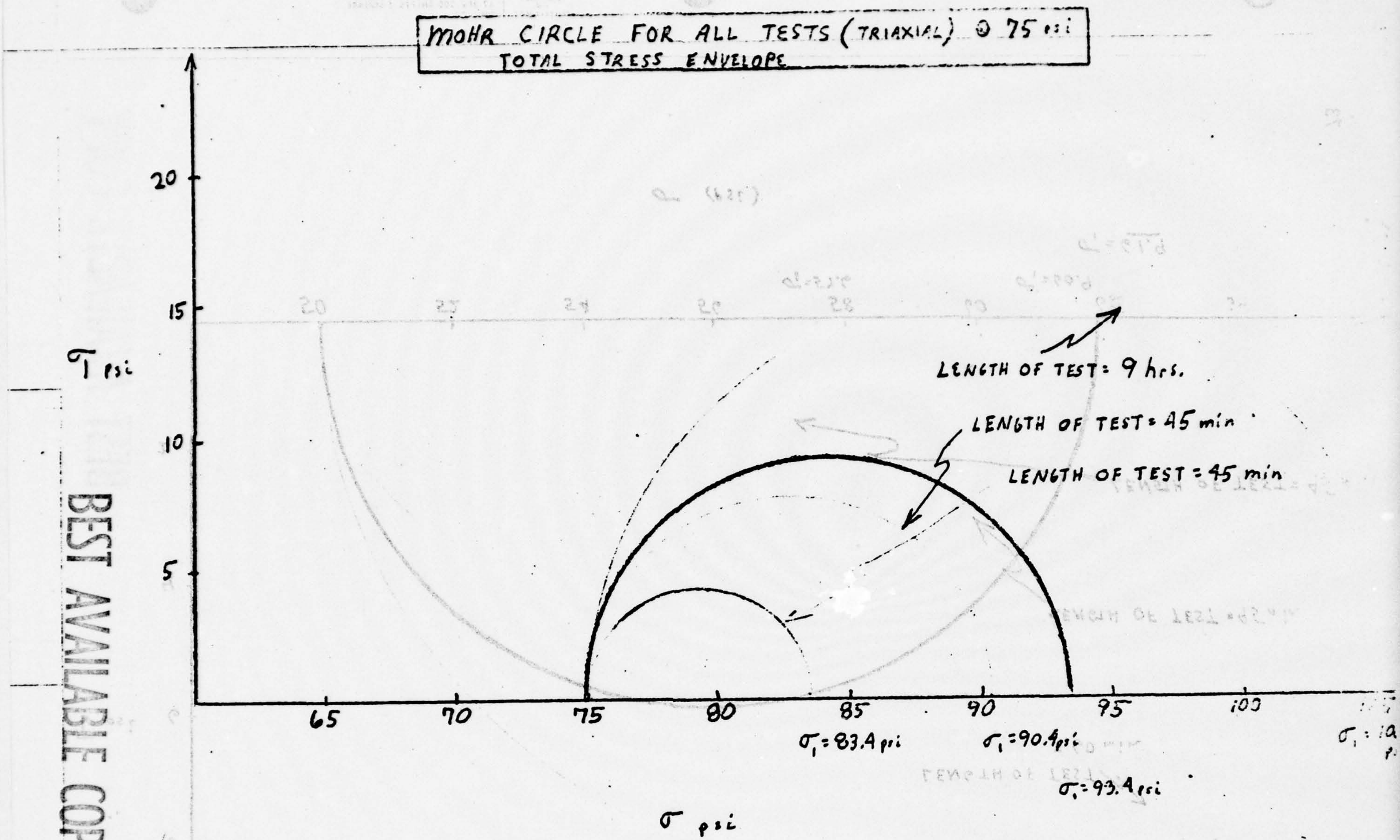

MOHR ENVELOPE FOR ALL TESTS @ 10, 25, 50, 75, 90 psi
TOTAL STRESSES, NORMALIZED VALUES
τ (psi)
30
20
10
10
20
30
40
50
60
70
80
90
100
σ (psi)


MOHR CIRCLE FOR TRIAXIAL TEST
TOTAL STRESS ENVELOPE $\sigma = 10$ psi
test time = 45 min
$\tau_{(psi)}$
4
3
2
1
9
10
11
12
13
14
15
16
$\sigma_3 = 10.0$ psi
$\sigma_1 = 13.4$ psi
$\sigma_{(psi)}$

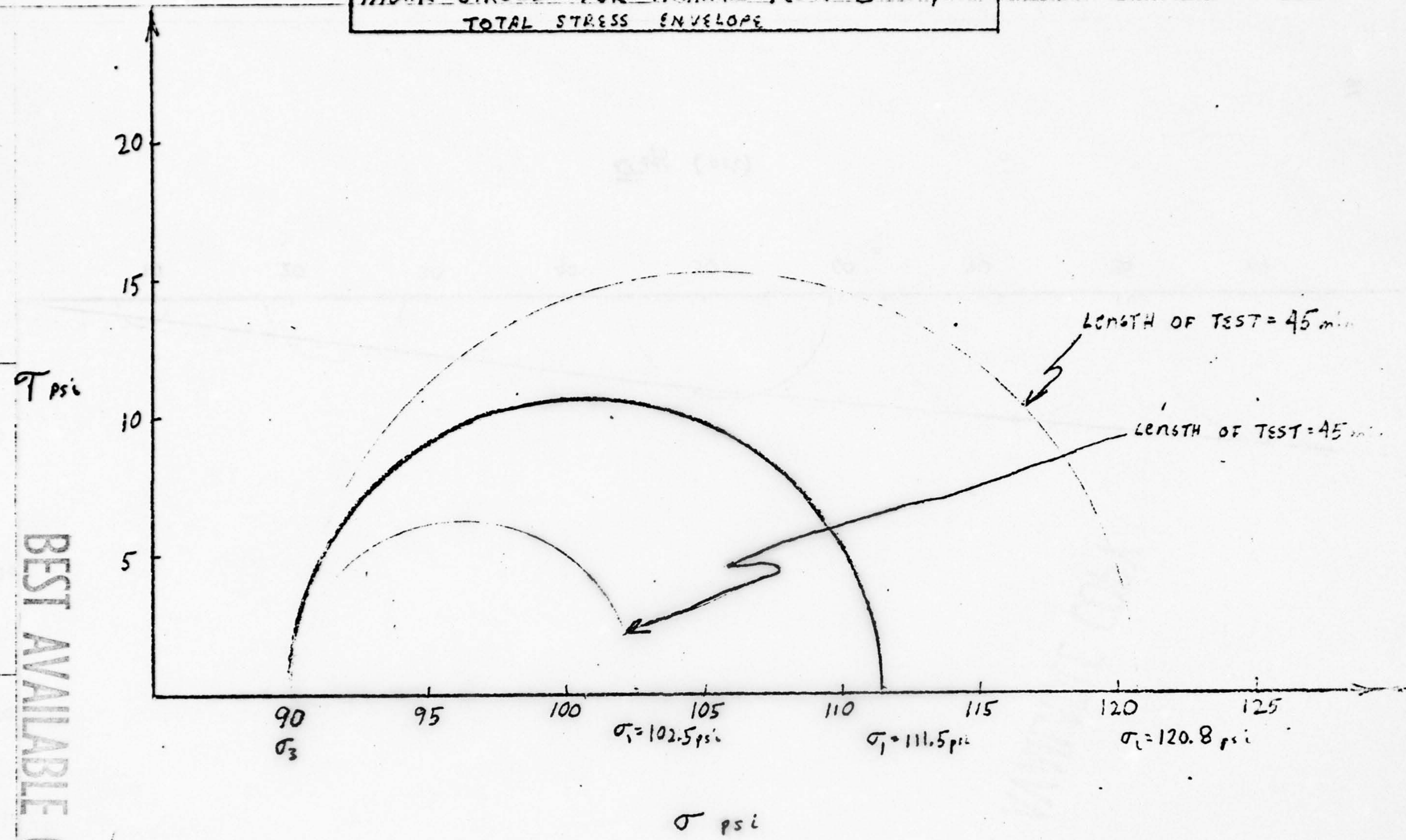
MOHR CIRCLE FOR ALL TRIAXIAL TESTS @ 25psi = σ_3
TOTAL STRESS ENVELOPE

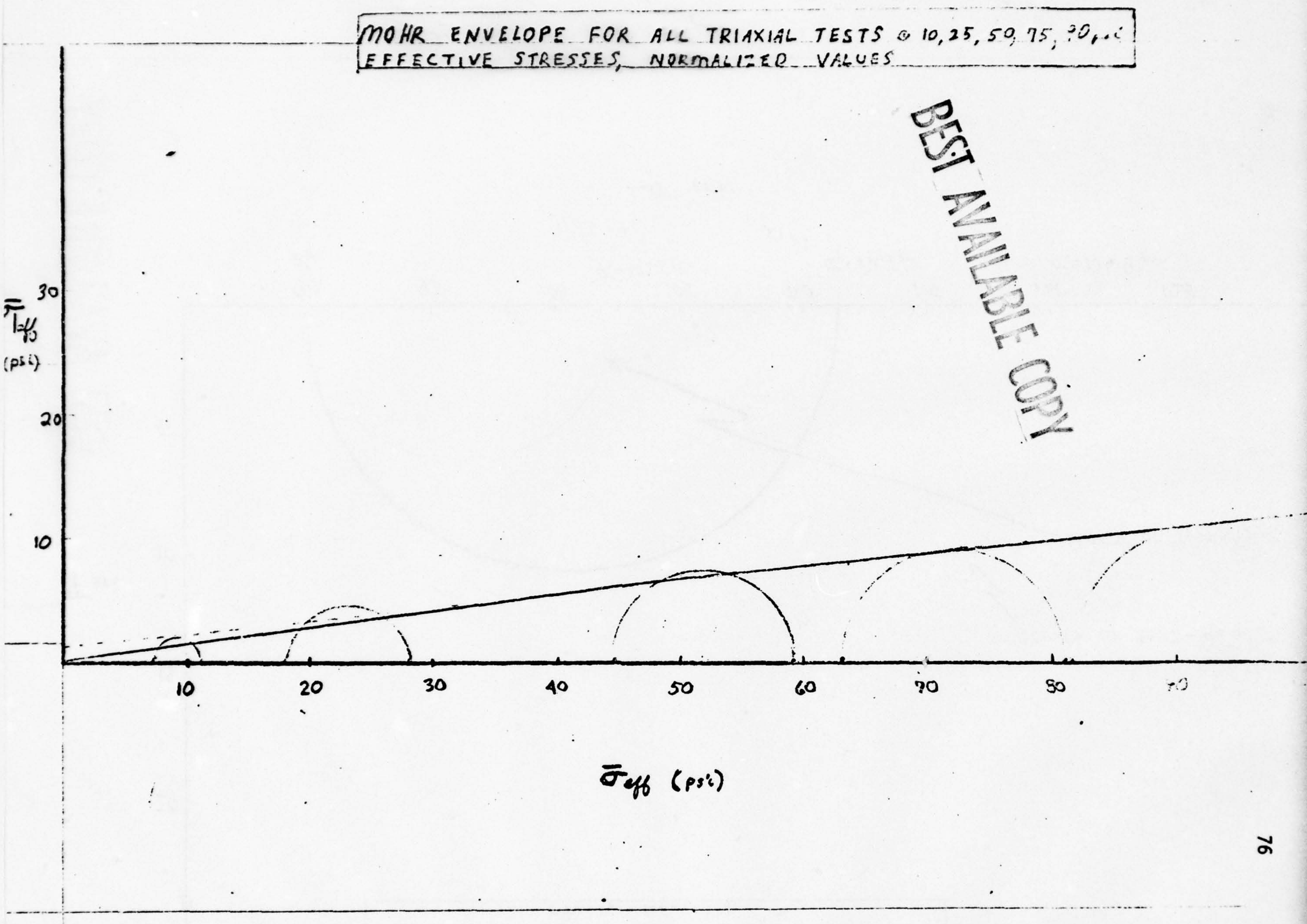



MOHR CIRCLES FOR TRIAXIAL TESTS @ 50 psi
TOTAL STRESS ENVELOPE
τ psi
8
6
4
2
LENGTH OF TEST = 60 min
LENGTH OF TEST = 45 min
LENGTH OF TEST = 45 min
50
52
54
56
58
60
62
64
σ₁ = 57.6
σ₁ = 60.9
σ₁ = 61.9
σ (psi)

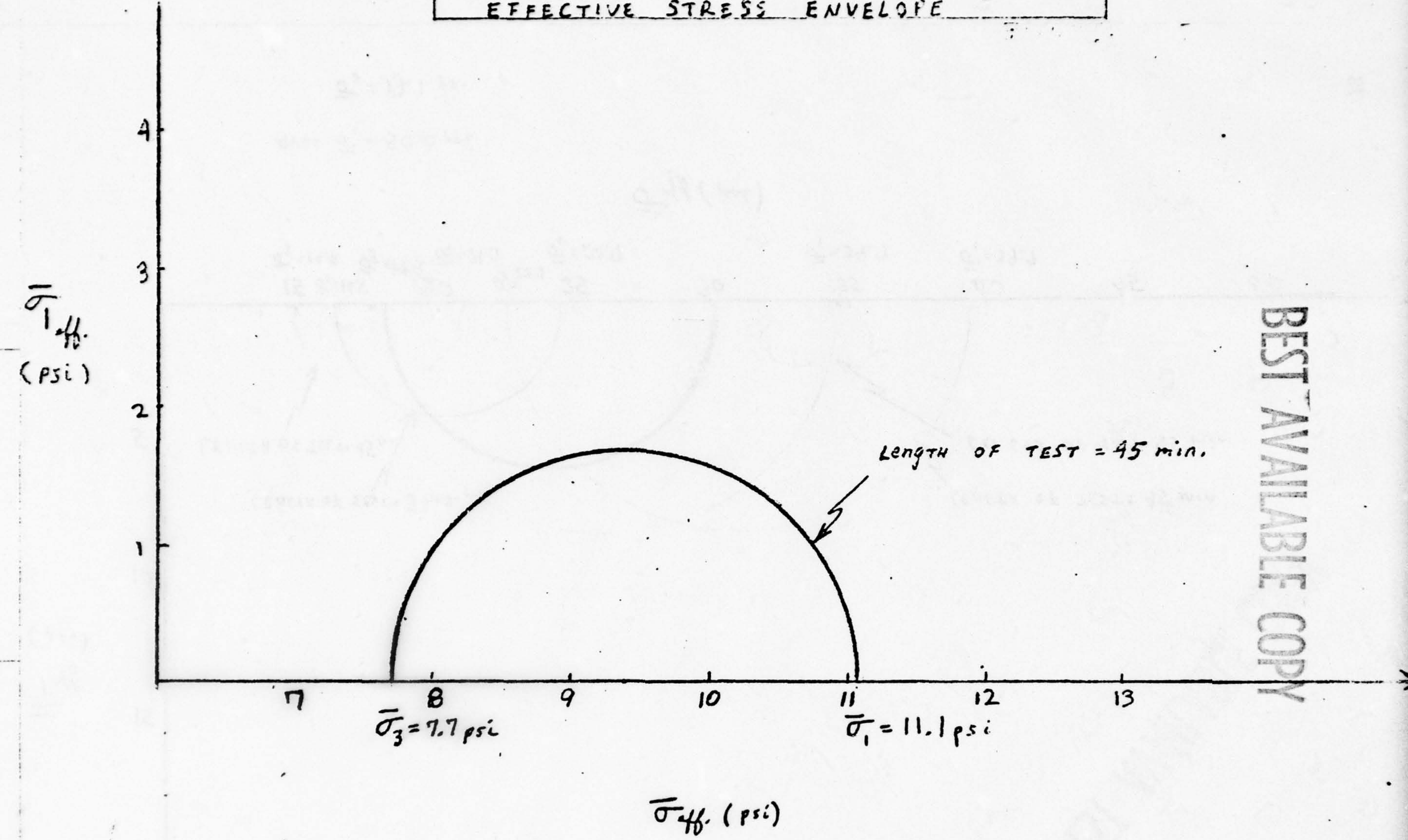

MOHR CIRCLE FOR ALL TESTS (TRIAXIAL) @ 75 psi
TOTAL STRESS ENVELOPE
τ psi
20
15
10
5
65
70
75
80
85
90
95
100
σ psi
σ1 = 83.4 psi
σ1 = 90.4 psi
σ1 = 93.4 psi
LENGTH OF TEST = 9 hrs.
LENGTH OF TEST = 45 min
LENGTH OF TEST = 45 min

MOHR CIRCLE FOR TRIAXIAL TESTS @ 90 psi
TOTAL STRESS ENVELOPE

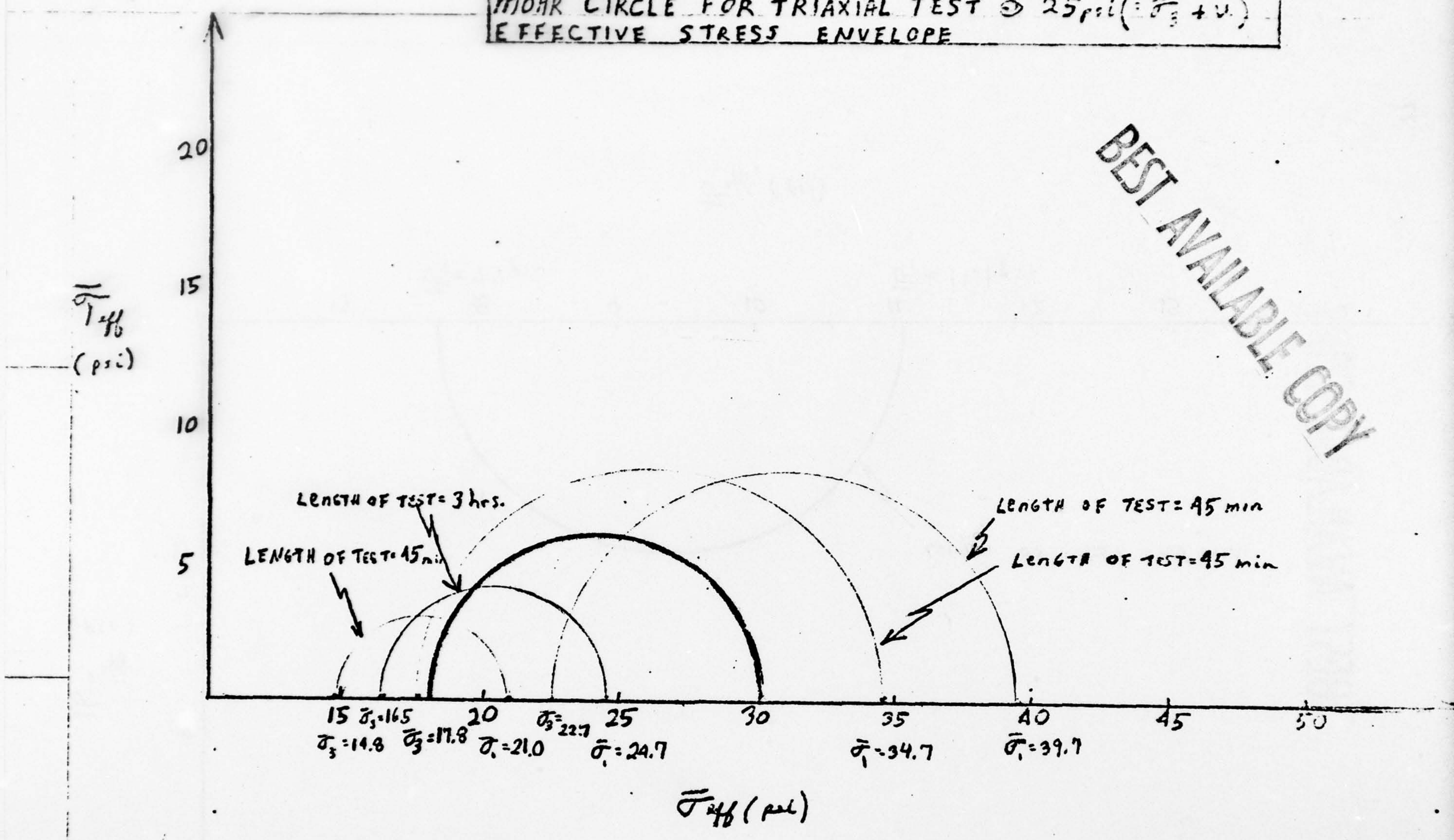



MOHR ENVELOPE FOR ALL TRIAXIAL TESTS @ 10, 25, 50, 75, 90 psi
EFFECTIVE STRESSES, NORMALIZED VALUES
$\bar{\tau}_{eff}$ (psi)
30
20
10
10
20
30
40
50
60
70
80
$\bar{\sigma}_{eff}$ (psi)

MOHR CIRCLE FOR TRIAXIAL TEST @ 10 psi
EFFECTIVE STRESS ENVELOPE



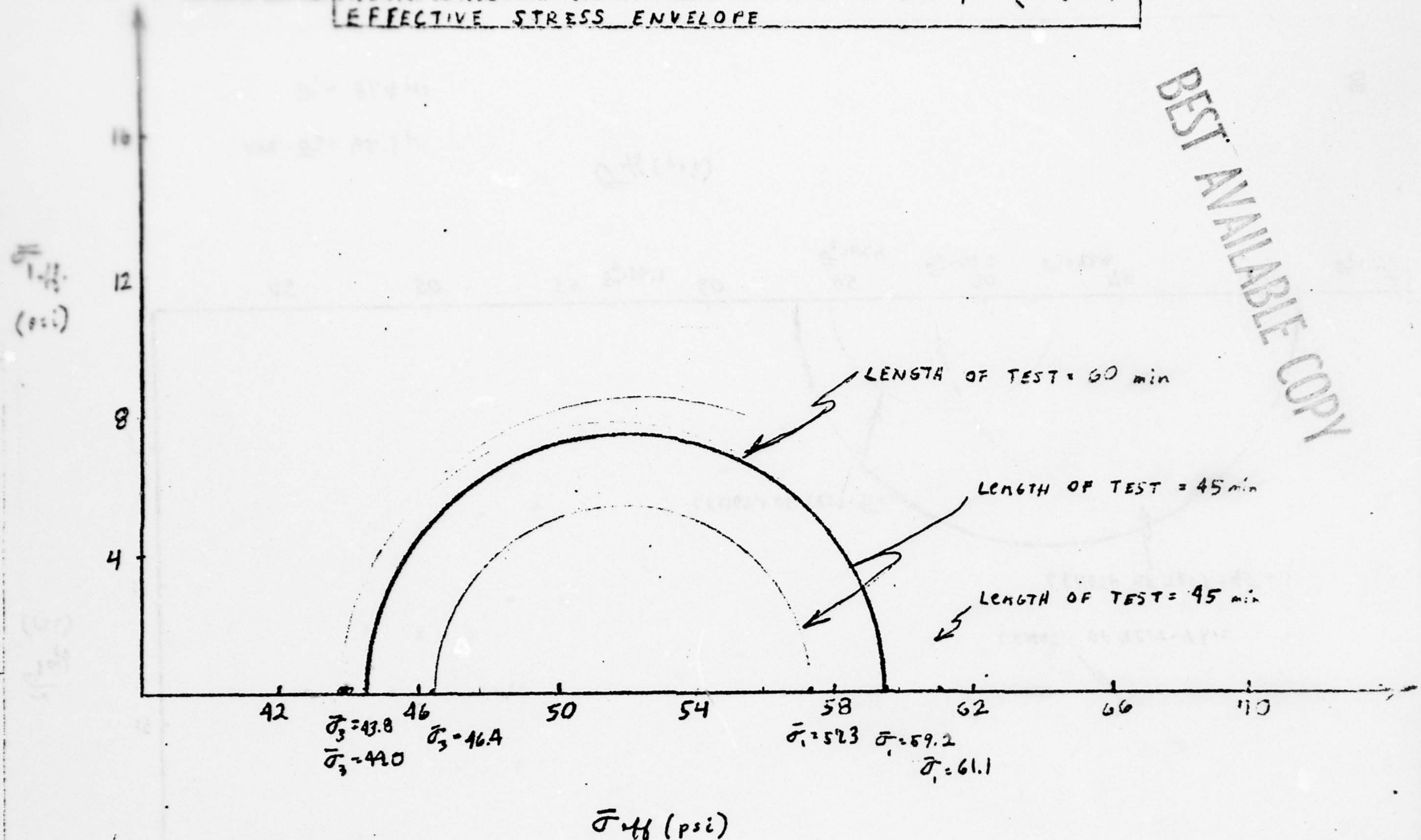
MOHR CIRCLE FOR TRIAXIAL TEST @ 25 psi ($= \bar{\sigma}_3 + u$)
EFFECTIVE STRESS ENVELOPE



AVG: $\bar{\sigma}_1$ = 30.0 psi

$\bar{\sigma}_3$ = 17.1 psi

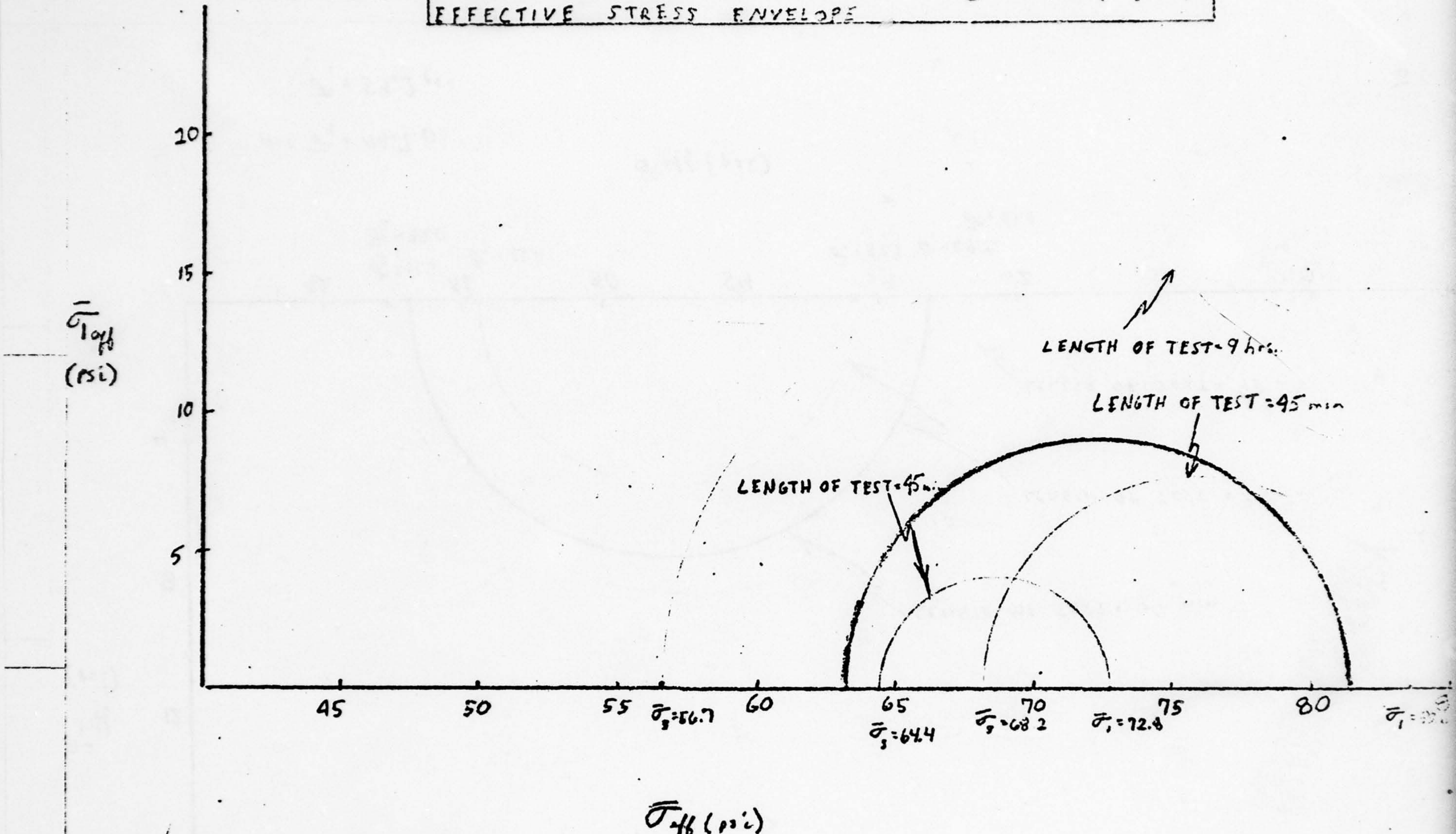
MOHR CIRCLE FOR TRIAXIAL TESTS @ 50 psi ($= \bar{\sigma}_3 + u$)
EFFECTIVE STRESS ENVELOPE



AVG. $\bar{\sigma}_3 = 44.7$ psi

$\bar{\sigma}_1 = 59.2$ psi

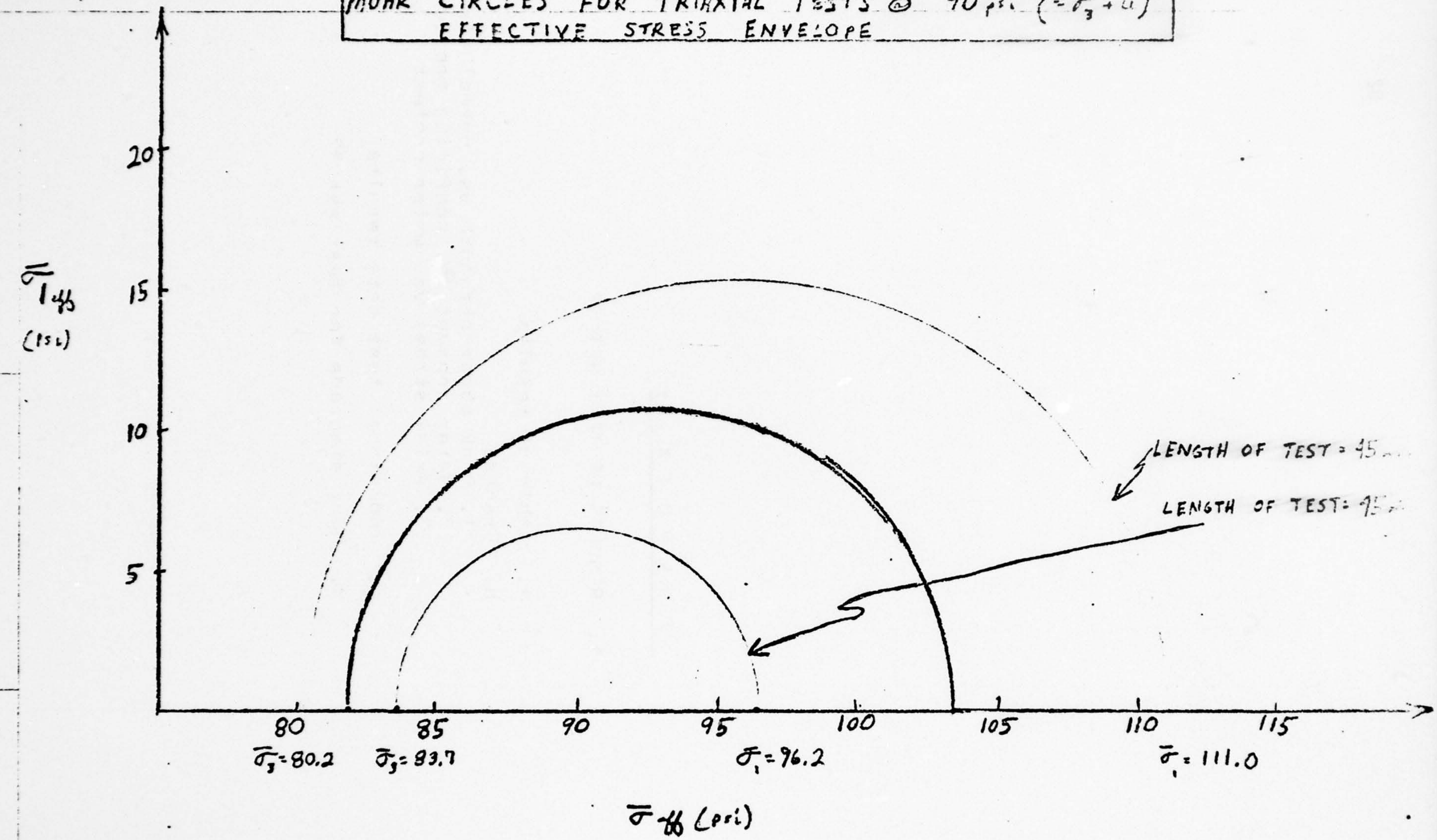
MOHR CIRCLE FOR TRIAXIAL TESTS @ 75 psi
EFFECTIVE STRESS ENVELOPE



AVG: $\bar{\sigma}_3$ = 63.1 psi

$\bar{\sigma}_1$ = 81.4 psi

MOHR CIRCLES FOR TRIAXIAL TESTS @ 90 psi $(=\bar{\sigma}_3 + u)$
EFFECTIVE STRESS ENVELOPE



AVG: $\bar{\sigma}_3 = 81.9$ psi

$\bar{\sigma}_1 = 103.6$ psi

APPENDIX H:

1. RESULTS OF TEST SET #2

    a. Table of results

    b. Graphs:
        1. Peak shear strength vs. normal stress
        2. Water content vs. confining pressure
        3. Axial stress vs. water content

    c. Individual test data results

    d. Mohr diagrams for test set #2

Test Set #2 Results

Water Content Results:

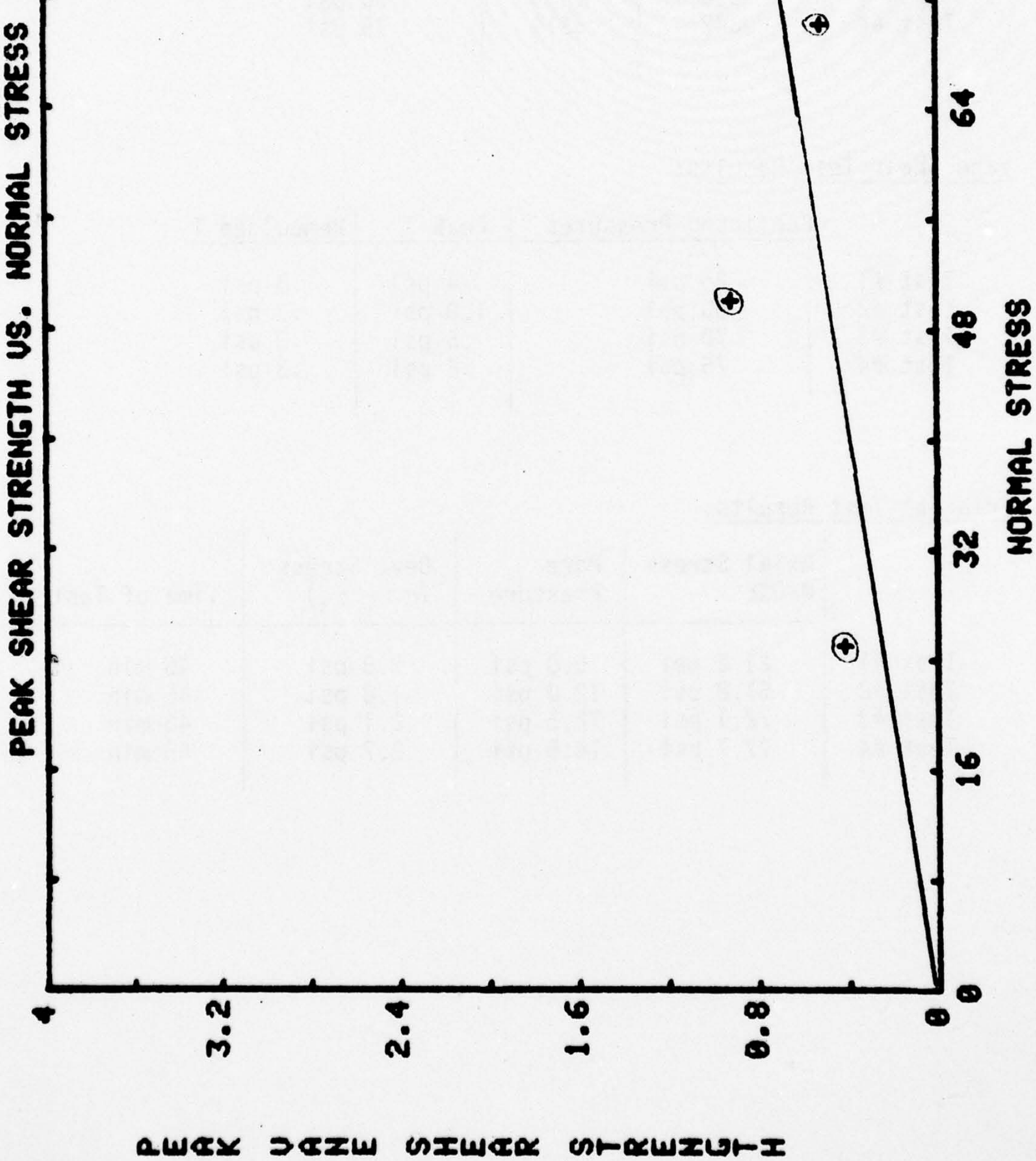
	Before	After	Confining Pressure
Test #1	.372	.333	25 psi
Test #2	.34	.329	50 psi
Test #3	.330	.319	70 psi
Test #4	.342	.319	75 psi

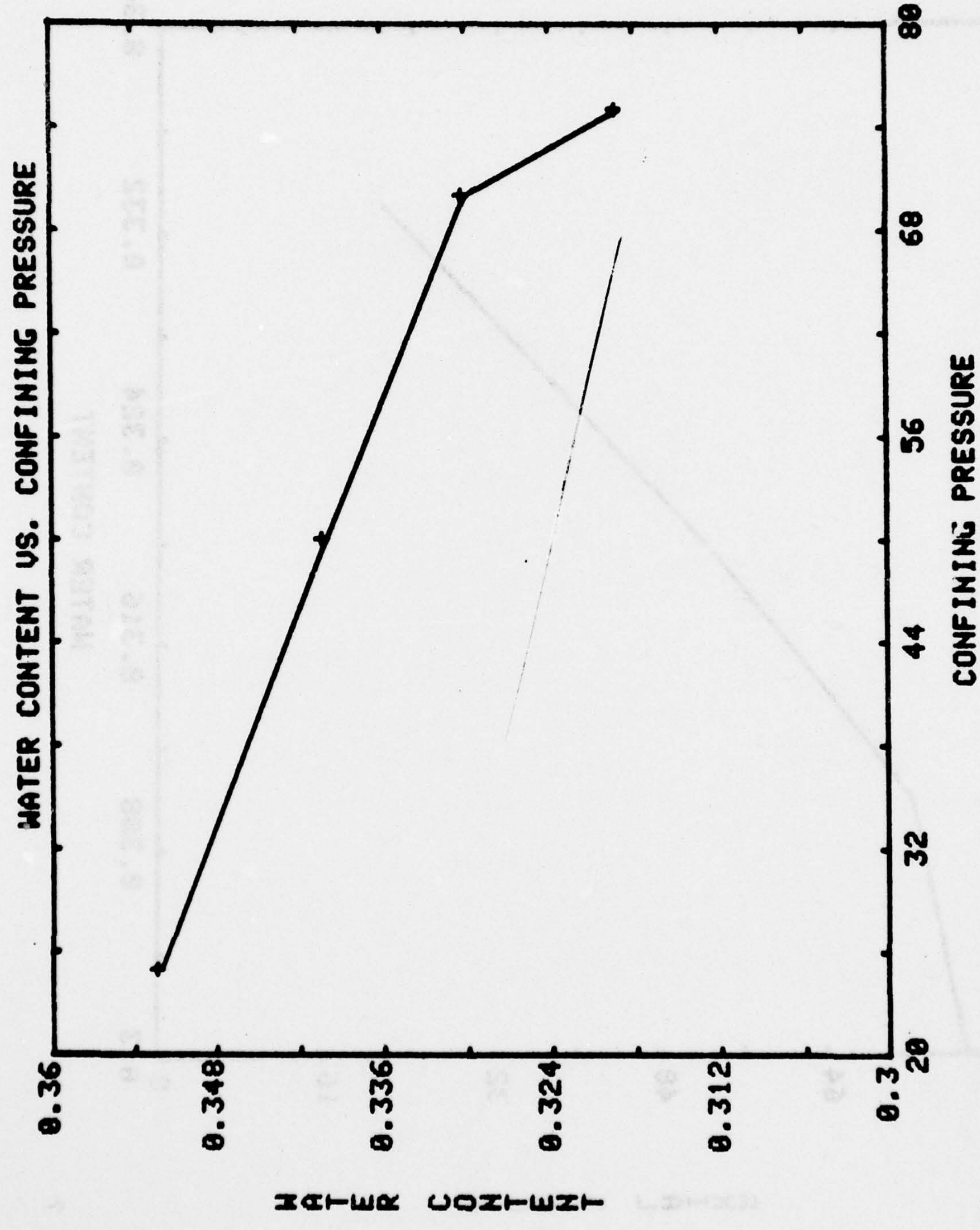
Vane Shear Test Results:

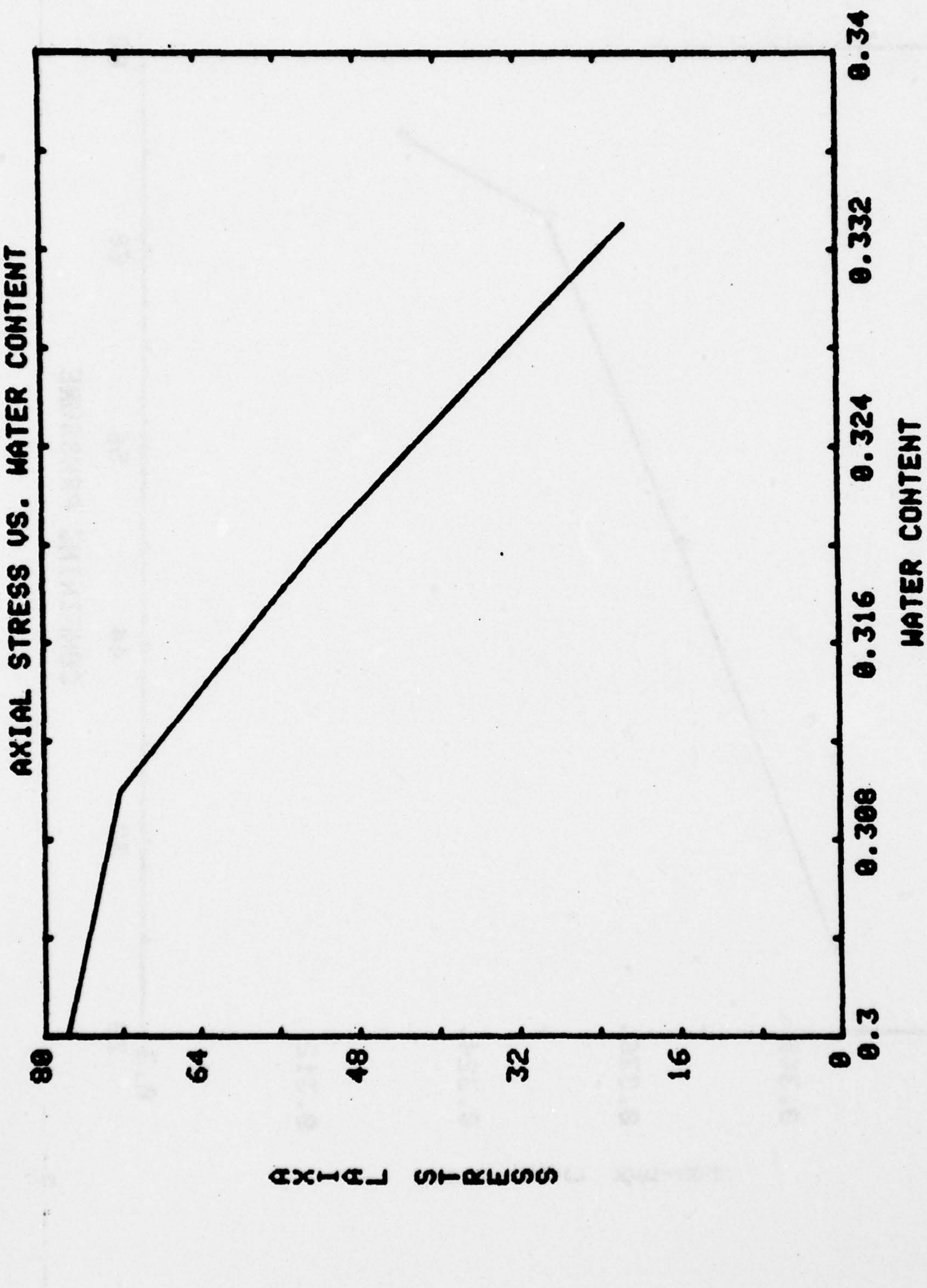
	Confining Pressures	Peak T	Remoulded T
Test #1	25 psi	.4 psi	.3 psi
Test #2	50 psi	1.0 psi	.3 psi
Test #3	70 psi	.5 psi	.3 psi
Test #4	75 psi	.6 psi	.3 psi

Triaxial Test Results:

	Axial Stress @20%E	Pore Pressure	Dev. Stress ($\sigma_1 - \sigma_3$)	Time of Test
Test #1	21.2 psi	5.0 psi	3.8 psi	45 min
Test #2	51.8 psi	12.0 psi	1.8 psi	45 min
Test #3	72.1 psi	12.5 psi	2.1 psi	45 min
Test #4	77.7 psi	14.5 psi	2.7 psi	45 min


PEAK SHEAR STRENGTH VS. NORMAL STRESS
NORMAL STRESS
0
16
32
48
64
80
PEAK VANE SHEAR STRENGTH
0
0.8
1.6
2.4
3.2
4


WATER CONTENT VS. CONFINING PRESSURE
WATER CONTENT
0.36
0.348
0.336
0.324
0.312
0.3
CONFINING PRESSURE
20
32
44
56
68
80


AXIAL STRESS VS. WATER CONTENT
AXIAL STRESS
WATER CONTENT
80
64
48
32
16
0
0.3
0.308
0.316
0.324
0.332
0.34

TEST #1 DATA SET #2

Water content analysis:

BEFORE		AFTER TEST	
wt. paper	= .9g	wt. paper =	.3g
wt. paper + wet soil	= 42.9g	wt. paper + wet soil	= 75.1g
wt. paper + dry soil	= 31.5g	wt. paper + dry soil	= 56.4
wt. water	= 11.4g	wt. water =	18.7
wt. dry soil	= 30.6g	wt. dry soil	= 56.1
water content	= .372	water content	= .333

CUT test data: P = 25 psi

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0010	4.45	.75	.165	2.5	.5
10	.0011	4.9	.82	.33	5.08	1.0
15	.0012	5.34	.9	.495	7.61	1.5
20	.0012	5.34	.9	.68	10.15	2.0
25	.0013	5.78	.97	.825	12.7	3.0
30	.0014	6.23	1.05	.99	15.23	3.5
35	.0015	6.67	1.12	1.155	17.76	4.0
40	.0016	7.12	1.20	1.32	20.3	5.0
45	.0018	8.01	1.35	1.5	23.0	5.5

Vane Shear Test Data

Peak τ = .4 psi

Remolded τ = .3 psi

TEST #2 DATA SET #2

Water Content Analysis:

Before

wt. paper	= .5 g
wt. paper + wet soil	= 51.7
wt. paper + dry soil	= 38.7
wt water	= 13.0
wt. dry soil	= 38.2
water content	= .34

After Test:

wt. paper	.3 g
wt. paper + wet soil =	34.2
wt. paper + dry soil =	25.8
wt. water =	8.4
wt. dry soil =	25.5
water content =	.329

CUT Test Data = P = 50 psi

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0012	5.3	.9	.165	2.5	1.0
10	.0011	4.9	.824	.33	5.08	2.0
15	.0013	5.8	.97	.495	7.61	3.5
20	.0015	6.68	1.12	.68	10.15	5.0
25	.0017	7.56	1.27	.825	12.7	6.5
30	.0019	8.45	1.42	.99	15.23	8.0
35	.0021	9.35	1.57	1.155	17.76	10.0
40	.0024	10.7	1.8	1.32	20.3	12.0
45	.0027	12.02	2.02	1.5	23.0	14.0

Vane Shear Test Data

Peak τ = 1.0 psi

Remoulded τ = .3 psi

TEST #3 DATA SET #2

Water Content Analysis:

Before

wt. paper	= .8g
wt. paper + wet soil	= 54.9
wt. paper + dry soil	= 41.1
wt water	= 13.8
wt. dry soil	= 40.3
water content	= .342

After Test:

wt. paper	= 6g
wt. paper + wet soil	= 45.1
wt. paper + dry soil	= 36.0
wt. water	= 11.3
wt. dry soil	= 35.4
water content	= .319

CUT Test Data = P_{lat} = 75 psi

Time (min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0008	3.56	.6	.165	2.5	1.5
10	.0014	6.23	1.05	.33	5.08	3.0
15	.0018	8.01	1.35	.495	7.61	4.5
20	.0020	8.9	1.50	.68	10.15	6.0
25	.0030	13.4	2.2	.825	12.7	8.0
30	.0023	10.235	1.8	.99	15.23	9.5
35	.0030	13.4	2.2	1.155	17.76	12.0
40	.0036	16.02	2.69	1.32	20.3	14.5
45	.0039	17.35	2.92	1.5	23.0	17.0

Vane Shear Test Data:

Peak τ = .6 psi

Remoulded τ = .3 psi

TEST #4 DATA SET #2

BEFORE		AFTER	
wt. paper	= .7g	wt. paper	= 1.0
wt. paper + wet soil	= 86.2g	wt. paper + wet soil	= 55.0
wt. paper + dry soil	= 69.0	wt. paper + dry soil	= 42.0
wt. water	= 21.2	wt. water	= 13.0
wt. dry soil	= 64.3	wt. dry soil	= 41
water content	= .33	water content	= .319

CUT test data: P_{lat} = 70 psi

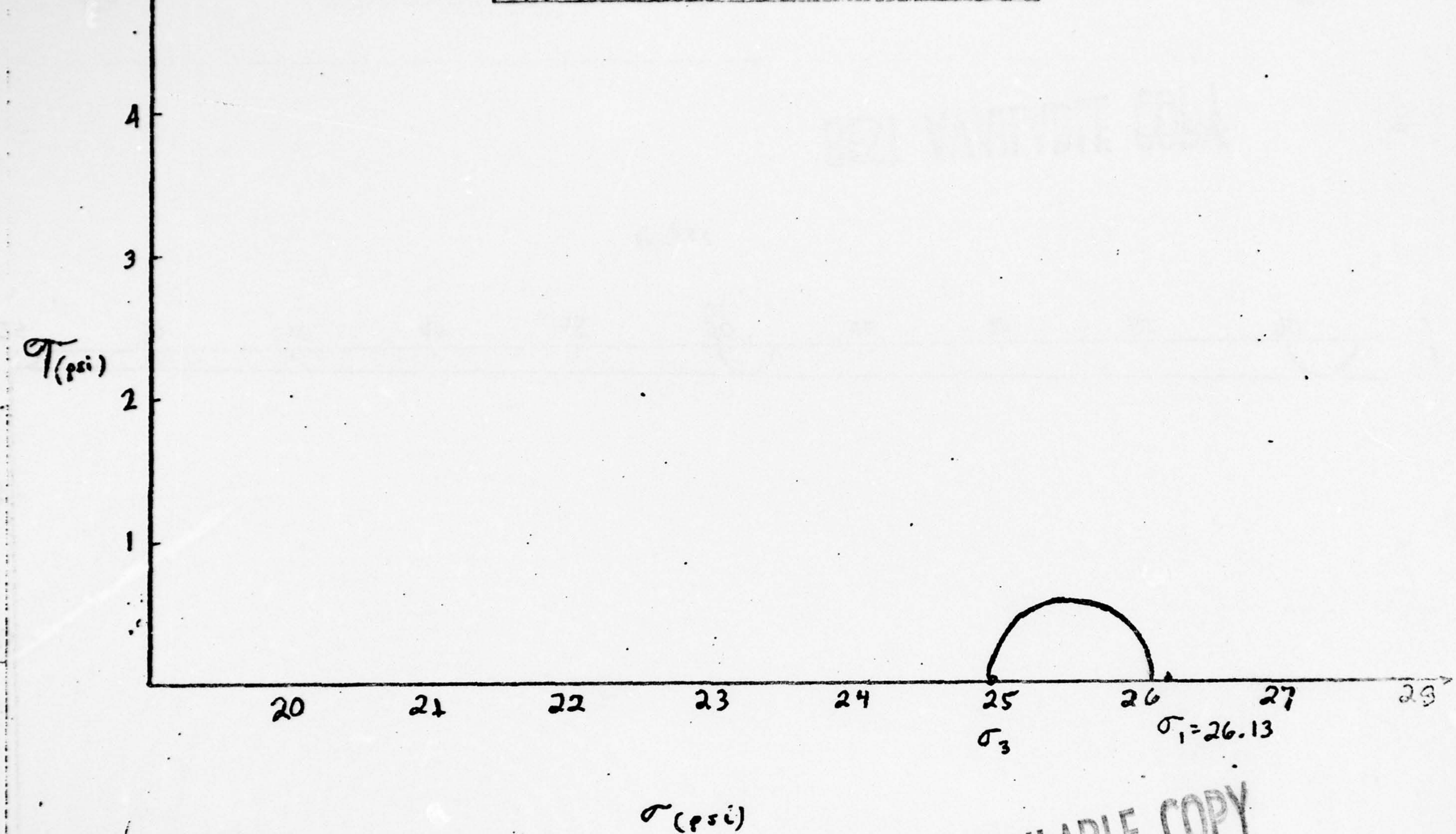
Time(min)	Stress Gage (in.)	Axial Load (lb)	Axial Stress (psi)	Strain Gage (in.)	Axial Strain (%)	Pore Pressure (psi)
0	0	0	0	0	0	0
5	.0005	2.23	.37	.165	2.5	1.0
10	.0009	4.0	.67	.33	5.08	2.0
15	.0012	5.34	.9	.495	7.61	4.0
20	.0015	6.67	1.12	.68	10.15	5.5
25	.0018	8.01	1.35	.825	12.7	7.0
30	.0025	11.12	1.87	.99	15.23	8.0
35	.0024	10.7	1.80	1.155	17.76	10.0
40	.0028	12.5	2.1	1.32	20.3	12.5
45	.0033	14.7	2.47	1.5	23.0	14.0

VANE SHEAR TEST DATA:

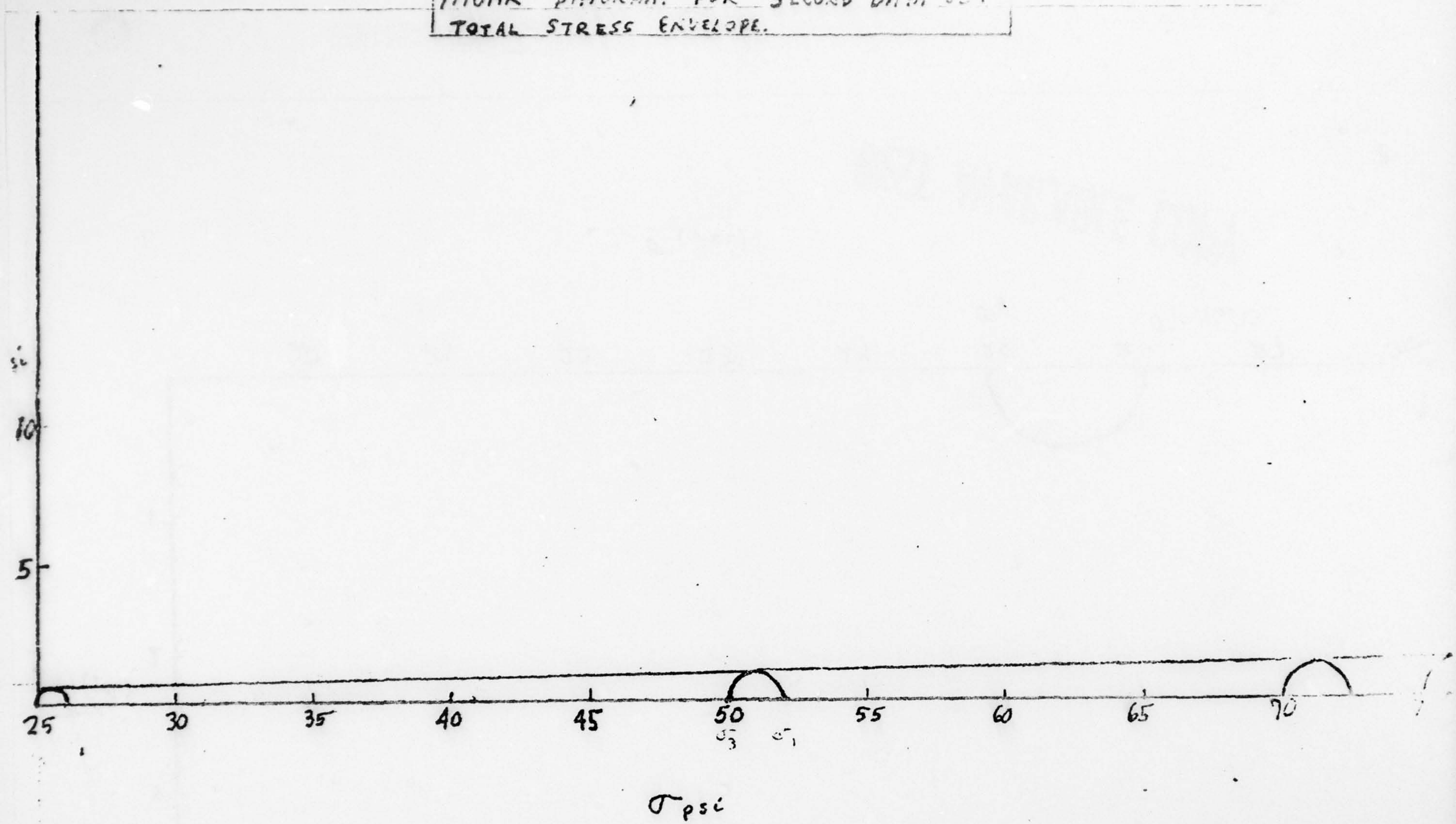
Peak τ = .5 psi

Remolded τ = .3 psi

MOHR DIAGRAM FOR TEST
TOTAL STRESS ENVELOPE



MOHR DIAGRAM FOR SECOND DATA SET
TOTAL STRESS ENVELOPE.



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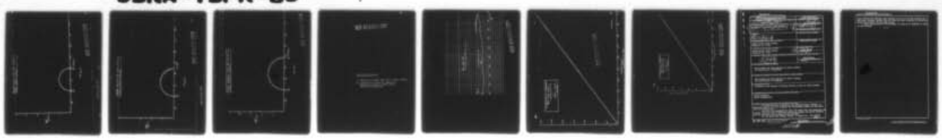

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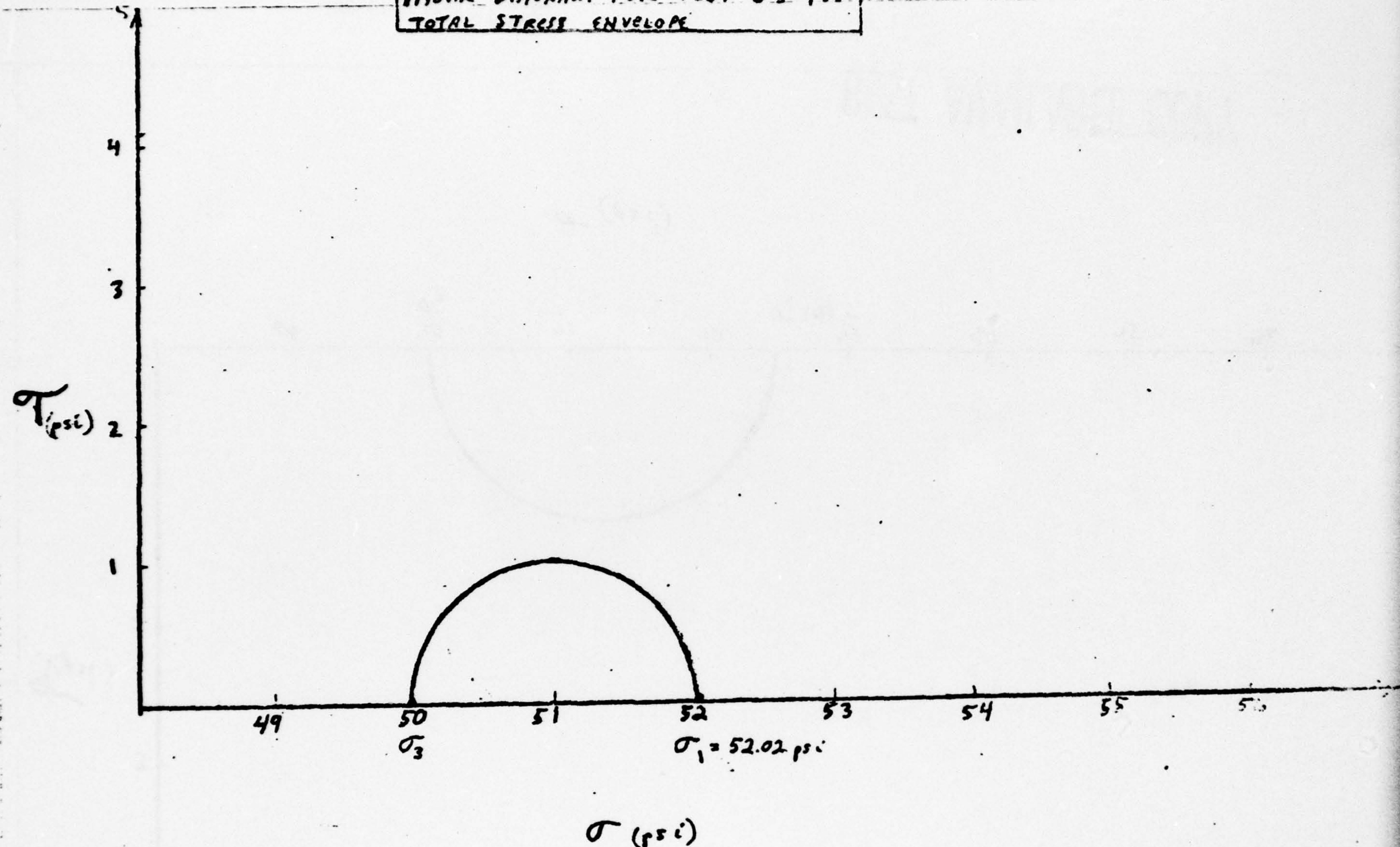
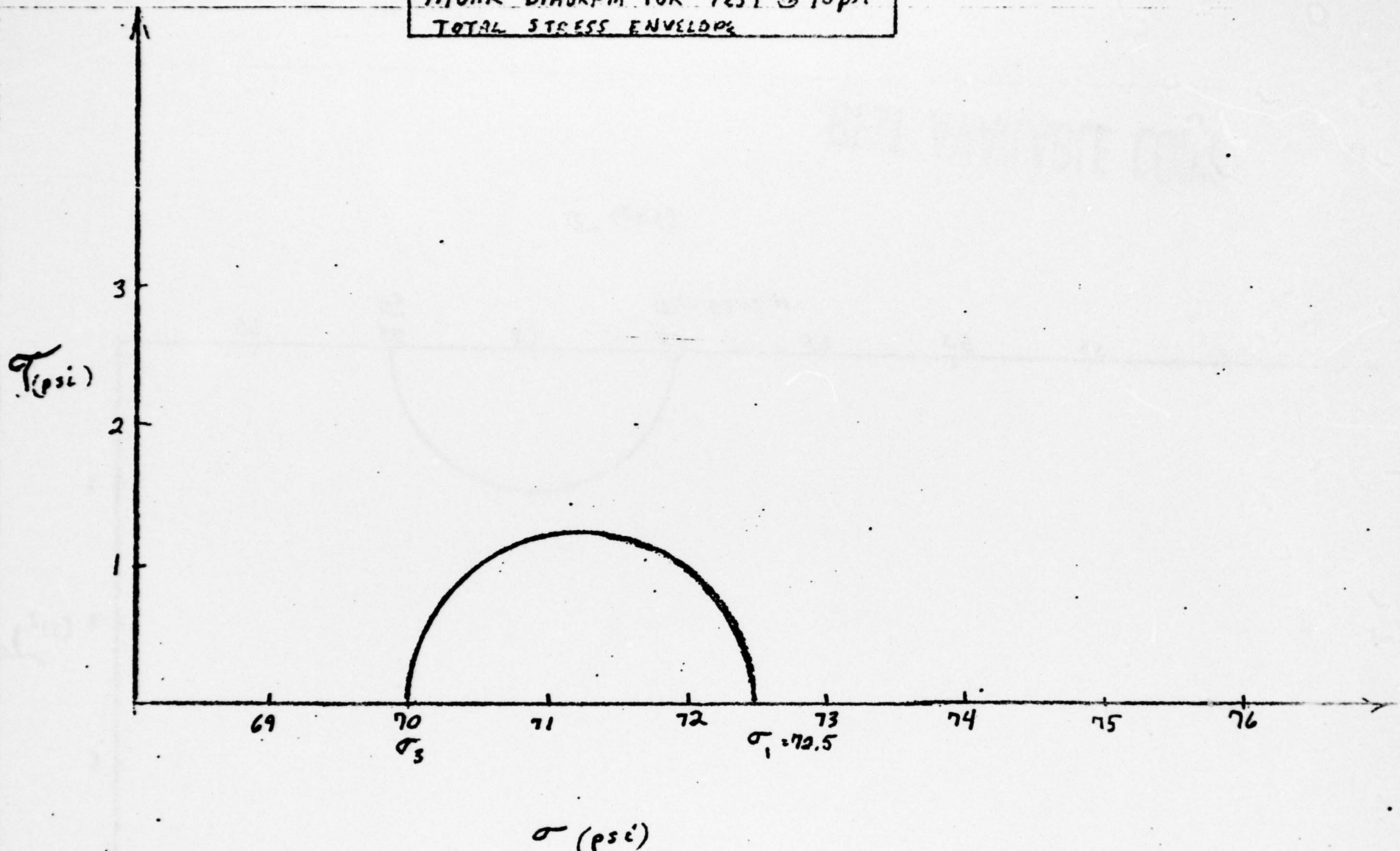
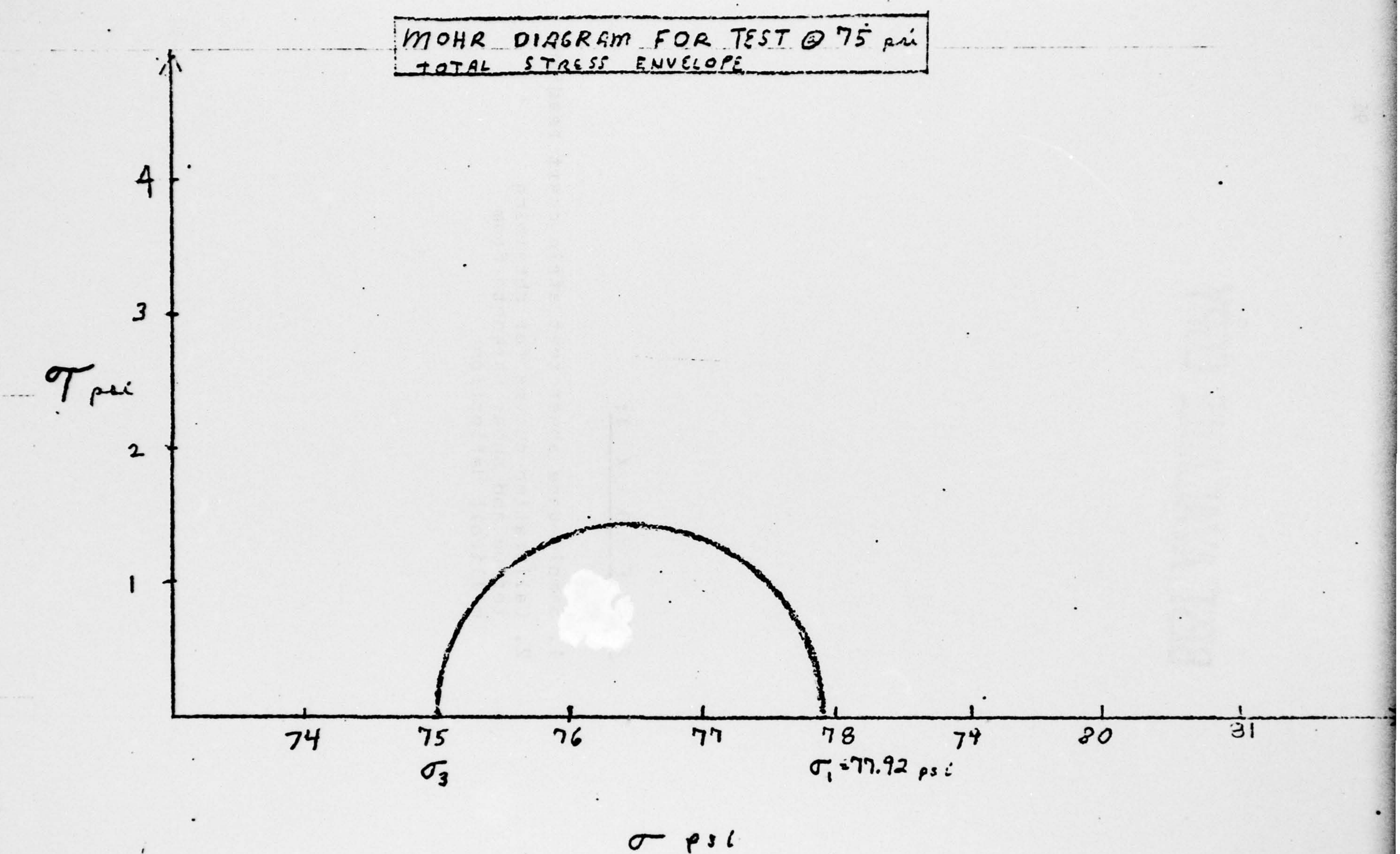
MOHR DIAGRAM FOR TEST @ 50 psi
TOTAL STRESS ENVELOPE



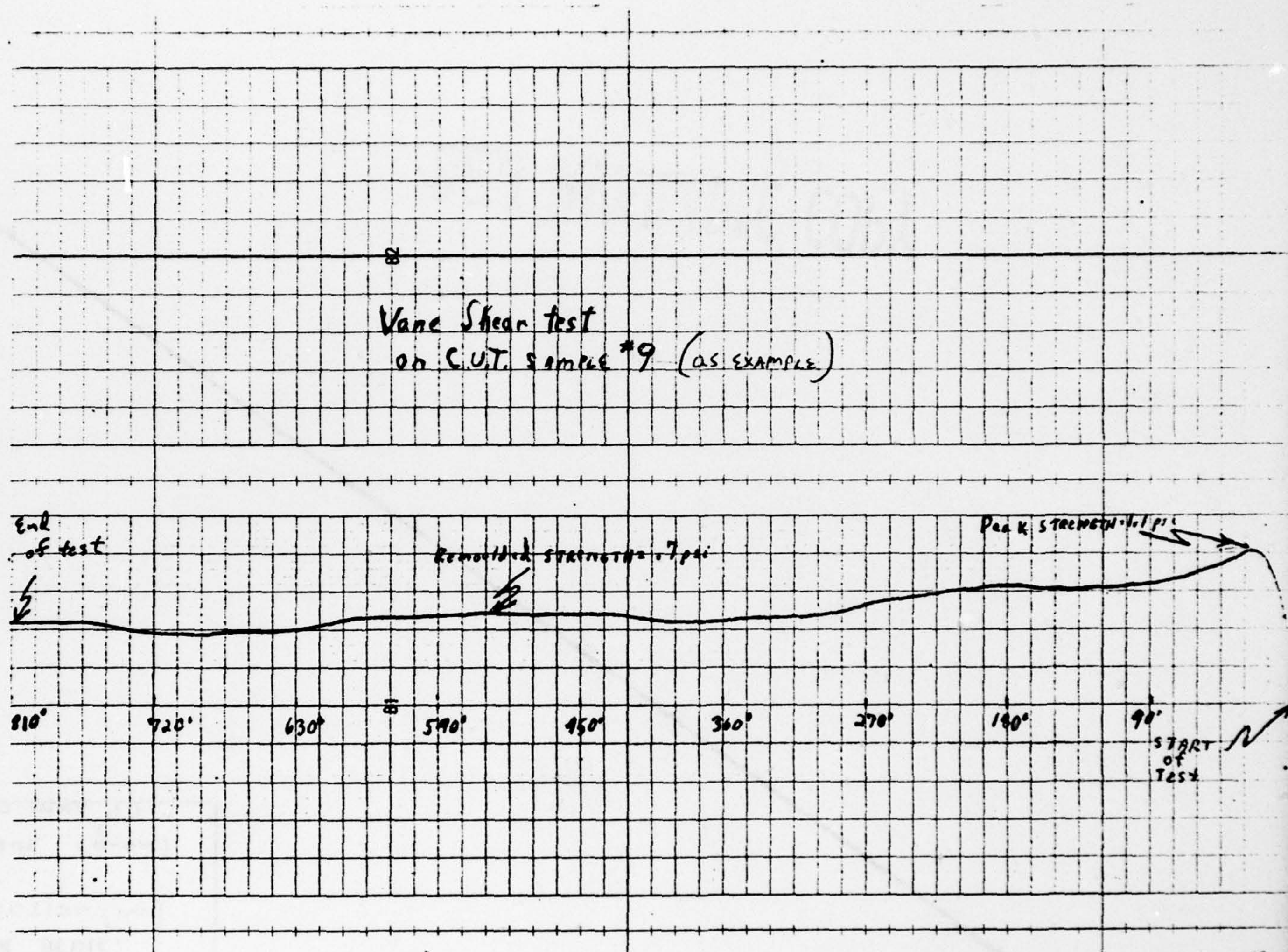
MOHR DIAGRAM FOR TEST @ 70 psi
TOTAL STRESS ENVELOPE

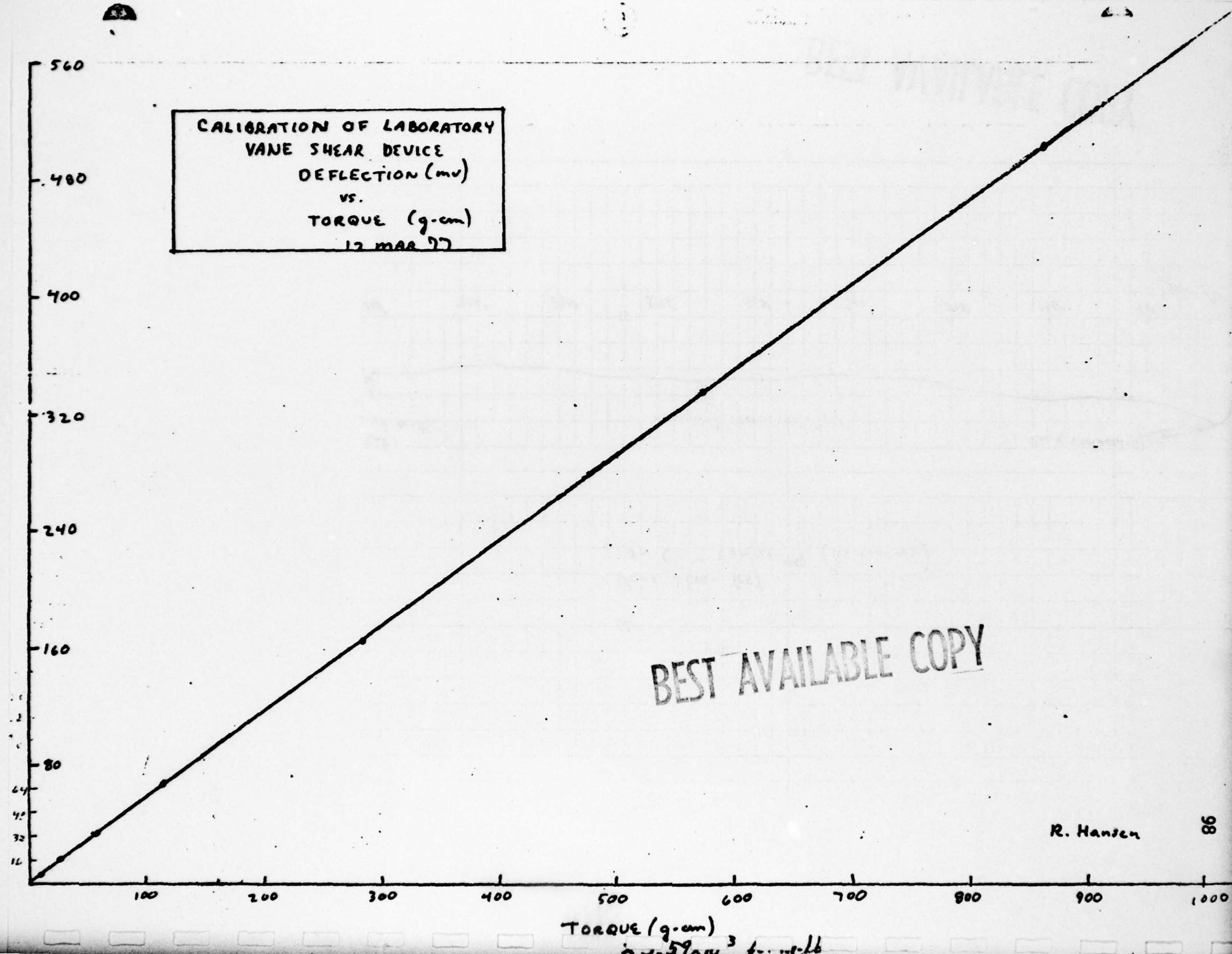


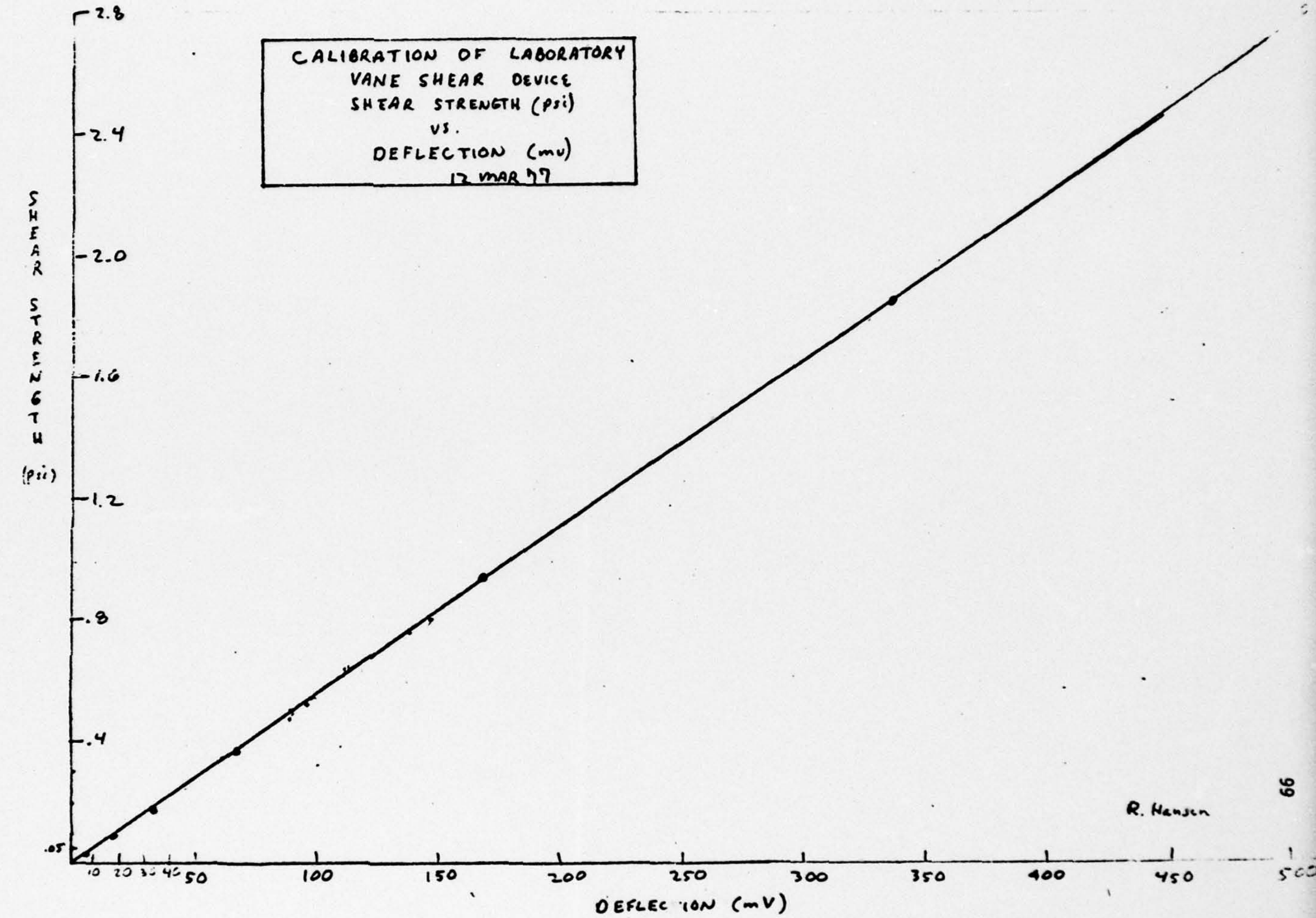

MOHR DIAGRAM FOR TEST @ 75 psi
TOTAL STRESS ENVELOPE
τ psi
1
2
3
4
74
75
76
77
78
79
80
81
σ3
σ1 = 77.92 psi
σ psi

APPENDIX I:

1. Sample vane shear test strip chart reading
2. Calibration curves for obtaining torque and shear strength from millivolt deflection


Vane Shear test
on C.U.T. sample #9 (as example)
End of test
Remoulded strength = .7 psi
Peak strength = 1.1 psi
START of Test
810°
720°
630°
540°
450°
360°
270°
180°
90°


CALIBRATION OF LABORATORY
VANE SHEAR DEVICE
DEFLECTION (mv)
vs.
TORQUE (g-cm)
12 MAR 77
560
480
400
320
240
160
80
100
200
300
400
500
600
700
800
900
1000
TORQUE (g-cm)
R. Hansen


CALIBRATION OF LABORATORY
VANE SHEAR DEVICE
SHEAR STRENGTH (psi)
vs.
DEFLECTION (mv)
12 MAR 77
SHEAR STRENGTH (psi)
2.8
2.4
2.0
1.6
1.2
.8
.4
.05
10 20 30 40 50 100 150 200 250 300 350 400 450 500
DEFLECTION (mV)
R. Hansen

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		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Robert Carl Hansen, Jr		8. CONTRACT OR GRANT NUMBER(s)
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18. SUPPLEMENTARY NOTES

Presented to the Chairman of Trident Scholars of the U.S. Naval Academy.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Marine sediments.
Marine geotechnique.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The study attempts to determine the laboratory shear strength of a particular marine soil, and evaluates the relationship between the vane shear test and triaxial test.

The writer has proceeded the usual vane shear tests and separately, the triaxial test and tried to find some correlation between the marine sediments and the terrestrial soil mechanics (data included).

For the particular sediment tested - a clayey silt - the initial

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tests indicate the vane shear peak strength to be 10 o/o of the triaxial test peak shear strength. However thus far, there has been virtually no correlation between the triaxial and vane shear tests.

Further testing needs to be performed, in order to be confident of these initial findings.

o - o